1999

A decision support system for planning and management of sustainable livestock production in the Midwest

Irene Mary Crawford
Iowa State University

A decision support system for planning and management of sustainable livestock production in the Midwest

by

Irene Mary Crawford

A thesis submitted to the graduate faculty

in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

Major: Water Resources

Major Professor: Udoyara Sunday Tim

Iowa State University

Ames, Iowa

1999

Graduate College
Iowa State University

This is to certify that the Master's thesis of

Irene Mary Crawford

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

To My Family

TABLE OF CONTENTS

CHAPTER 1. GENERAL INTRODUCTION

Introduction

Contamination of water resources is a particular concern for health, recreational, and environmental quality. Groundwater is the major source of drinking water for more than 90% of rural households and 75% of the cities in the United States (Goodrich et al., 1991). Groundwater pollution in the form of nitrates in drinking water presents significant health threats. Excess nutrients from over-application and improper handling and disposal of manure can lead to stream water contamination which can lead to excessive plant and algae growth that can deplete oxygen supplies in water and result in fish kills and aesthetically impaired lakes.

Nutrient leaching and runoff are a concern because of the large amounts of animal waste produced in the United States. From 1987 to 1997 the number of swine produced in the United States increased from 58.2 million to 60 million. In 1998, 1.7% of the swine operations in the United States raised 42% of the animals (USDA-NASS, 1998). Production of animal waste from these sites is often greater than the crop nutrient demand or the land base available for land application. This rapid expansion of swine production has led to increased environmental concerns.

The public is also raising concerns about atmospheric pollution from livestock facilities. Odor nuisance complaints related to livestock production have increased significantly during the past decade. The strongest public opposition to confined and concentrated livestock production has focused on offensive odors released from hog barns, manure-collecting lagoons, and land application sites. Neighbors complain that livestock odors adversely influence their quality of life, cause yet unknown long-term health problems, and significantly reduce real estate property values.

Many counties are pursuing expansions in livestock production as an economic development strategy. Thus, there is a need for tools and decision support systems (DSS) to guide the producer and decision-maker in choosing management practices that are economical, environmentally sound, and socially acceptable. As the nature of where to site a livestock production facility is spatial it seems reasonable to adopt current and emerging computer simulation models and geospatial technologies, such as geographic information systems (GIS) to develop solutions to these problems.

Literature Review

The Environmental Protection Agency has cited agricultural production, including livestock and crops, as the major source of non-point source pollution (EPA, 1997). Concentrated livestock production facilities, in particular, have recently come under intense scrutiny from legislators, environmental regulators, and the general public. Because crop and livestock production are important components of the economy of many states, including Iowa, there is a need to implement sustainable livestock production systems that not only enhances economical growth of these states, but also minimizes potentially adverse impacts on the environment.

Recent advancements in computer technology now provide the tools for rapid analysis of massive amounts of data needed to guide resource managers or producers in delineating sites for sustainable livestock production. In particular, recent developments in geographic information systems (GIS), that offer the tools for efficient handling, manipulation, and analysis of spatial information, have substantially improved the capabilities for the identification of land areas suitable for siting and planning sustainable livestock production systems. In this section I provide a literature review that summarizes relevant previous and current research related to the siting and planning of livestock production facilities, and the evaluation of environmental consequences of production systems. Also discussed are the analytical tools (e.g. information systems, computer models, theories, and concepts) that are widely used in evaluating the potential impacts of livestock production on environmental quality.

Scenario (or "what if") analysis is a reasonable concept to evaluate the impacts of livestock production facilities and human activities on the environment and to find acceptable solutions or compromises to promote sustainable livestock production in the Midwest. Allowing a decision-maker to investigate a feasible set of decision alternatives and to iteratively find an acceptable solution for land management analysis requires a set of tools that support rapid and comprehensive analysis and comparison of different scenarios. Model-based decision support systems (DSS) have been widely used to enhance these analyses (Wolfe et al., 1990; Hendrix and Buckley, 1992; Jain et al, 1995). A DSS is a computer-based system that helps the decision-maker utilize data and models to solve unstructured problems (Sprague and Carlson, 1982). Selecting a suitable site for planning livestock production systems is typically an ill-structured problem (Arentze, et al., 1996), as there are several conflicting objectives and uncertainties involved in the analysis and selection of the sites. Potential problems in livestock facility planning may include conflicts of environmental and economic objectives as well as uncertainties about the formulation of goals and their relative weights (Armstrong et al. 1991; Densham, 1991). Uncertainties also exist on the consequences of alternative management actions. Using a mathematical representation of the real-world system, algorithms are employed in the DSS to generate large amounts of information in support of the decision-making process. Advantages of a DSS are that data storage is standardized and that computer simulation provides a single organized approach (Leung, 1997).

The key characteristics of DSS are that they: (1) incorporate both data and models; (2) designed to assist managers in semi-structured or unstructured tasks; (3) support rather than replaces management judgements; and (4) improve the efficiency with which decisions are made (Grimshaw, 1994). A spatial decision support system (SDSS) is similar to a DSS except for its emphasis on capturing and processing spatial data and for solving spatial problems (Leung, 1997).

Many SDSS have been developed to improve environmental and natural resource management decision-making. Potential applications of SDSS in agriculture include: use of SDSS to evaluate farming practices in croplands (Yakowitz et al., 1993) and the management of grazing on rangelands (Lane et al., 1991).

Wang (1992) developed a DSS to delineate areas suitable for vegetable production in Hangzhou, China, on the basis of natural, social, and economic factors. The DSS was developed to locate vegetable farms in areas that would increase productivity, increase total net income to farmers, and reduce total land area required for production. Smith et al. (1997) developed a DSS to assist producers using conservation practices to ensure acceptable planting performance by providing recommendations and suggestions that producers could use to improve their production system. The system was customized to specific farm situations and included a set of management practices available to producers from planting to harvesting.

Integrating a DSS with GIS presents a reasonable framework for developing an effective and efficient DSS for the planning of livestock production systems. An advantage of coupling a DSS with a GIS is that the data can reflect as wide a range of spatial and temporal conditions as the database permits. GIS technology is a cost-effective and efficient tool for spatial data management enabling users to collect, compile, store, analyze, and display disparate information within a digital environment (Burrough, 1986; Goodchild, 1991). The speed and consistency with which GIS operates are reasons that it has had an enormous impact on virtually every field that manages and analyzes spatially distributed data. In the past, the largest impediments to the expanded use of GIS by the modeling community was the user-friendliness issue (Steyaert, 1996), as well as the cost of workstations. But with the trend towards desktop computers, the use of GIS has increased significantly in the last few years (Lee, 1997). This is due to the increase in speed and high performance of microcomputers and the reduction in cost. Environmental Systems Research Institute's (ESRI) ArcView GIS is an example of one GIS software taking advantage of the trend towards desktop computers.

The siting of livestock production facilities and the over-application of manure as a result of insufficient land base can have far-reaching impacts on environmental quality. According to hydrogeologists, connected ponds of groundwater 1.5 to 5 meters below the surface lie under much of north central Iowa. Hog lagoons are required to be at least 60 cm above the water table, but some are not (Kelly, 1996). Underground water surrounding lagoons can weaken lagoon berms, and leaked contaminants can spread a few miles over time. A GIS can be used to effectively handle large volumes of data related to livestock production and manure application and to narrow down the large areas under consideration to a set of suitable sites that meet environmental and socio-economic criteria. A GIS approach to selecting suitable livestock production sites incorporates spatial attributes that influence a sites vulnerability to both surface and groundwater pollution.

As the nature of where to site a livestock production facility is spatial, it seems only natural to use the capabilities of GIS. GIS has previously been used in site selection processes to narrow candidate sites. For example, the U.S. Department of Energy used GIS to select sites for a nuclear waste repository (U.S. DOE, 1986). Hendrix and Buckley (1992) used GIS techniques to select optimal locations for sewage waste, while Cruz (1993) and Basagoglu et al. (1997) used the GIS technology to identify candidate sites for a solid waste disposal facility in Turkey and the Philippines, respectively.

Cox and Madramootoo (1998) used GIS to develop conservation-oriented watershed management strategies in Saint Lucia. A soil loss model was executed within a GIS environment to evaluate agricultural management strategies in terms of soil loss. The procedure developed has contributed to the evolution of a DSS to guide natural resource planning in Saint Lucia.

Gar-On Yeh and Li (1998) developed a sustainable land development model using GIS. The model assessed land areas for suitability for sustainable agricultural production. If a land area was suitable for agricultural production, than it was set aside and protected from urban sprawl. The model is used as a DSS for sustainable land development in areas of the world that are under great pressure of rapid urban growth.

Wolfe et al. (1990) used a GIS to determine locations of dairies as well as areas for agricultural waste disposal. Locating optimal sites for dairy production required the consideration of many factors that are spatially distributed across the landscape, including topography, soils, geology, and wind characteristics.

Hendrix and Buckley (1992) utilized a GIS to delineate environmentally sound land areas for the application of municipal wastes. Land suitability for municipal waste disposal was evaluated using factors representing soils, topography, and land use, which were integrated with information about the biological, chemical, and physical properties of the waste. Results of the analyses were combined with a set of factors that reflect the social and political constraints of applying wastes on land. Brookes (1997) used raster suitability maps to locate regions (rather than individual cells) for siting wildlife reserves with different spatial characteristics, while Furst et al. (1993) developed a GIS based DSS for the management of groundwater.

The numerous studies conducted to develop and improve analytical tools for resource management have been conducted because of the growing concern for environmental degradation. In recent years, GIS technology has been applied effectively to estimate non-point source pollutant loads from agriculture. In the Galveston Bay National Estuary Program, GIS was used to calculate non-point source loads, map the location of generated non-point source loads, and rank loadings by subwatershed (Newell et al., 1992). Impact of livestock production in Pennsylvania was assessed by using GIS map overlays of watershed boundaries, slope, soils, and land cover information with animal density and climatic factors Mertz (1993). McMillen and Gorman (1993) and Quinlan and Simmons

(1993) combined land use analysis with complex water quality models and GIS to evaluate management options for non-point pollution control in North Carolina and Oregon, respectively.

Swine manure contains nitrogen (N), phosphorus (P), potassium (K), as well as other micronutrients, all of which are vital to corn (Zea mays L.) production. According to a National Corn Handbook release (Klausner et al., 1991) about 70-80% of N, 60-85% of P, and 80-90% of K fed to animals is excreted in the form of manure. Some estimates indicate that about 4.5 kg of N is available per ton of manure produced, whereas other estimates show only 2 kg of available N for each ton of manure. A 1995 summary report from the Iowa Farm and Rural Life Poll indicates that about 49.8% of Iowa farmers who apply manure to their fields take credit for the nutrient content of the manure (Lasley, 1995). The objectives of animal waste application to the soil are disposal and nutrient recycling. In addition to providing valuable nutrients to plants, manure improves soil tilth and water-holding capacity, and increases resistance to crusting and compaction (Letson and Gollehon, 1996). Although beneficial for crop production, over-application of manure can have detrimental effects on both surface and groundwater quality. Nutrients, primarily N and P, are responsible for the eutrophication and reduced aesthetics of rivers, lakes, and estuaries (Puckett, 1995) and the accelerated nitrate-N loading in the Mississippi River has been associated with increased spread and severity of hypoxia within the Gulf of Mexico (Rabalais et al, 1996). Hynes (1971) noted that excessive loading of N and P in surface water could lead to an increase in plankton, diatoms, and green algae, and, ultimately, to the eutrophication of surface waters. Eutrophication, which occurs because sunlight cannot pass through the thick layers of algae, is the dying and oxygen consuming decay of plants on the floor of the water body, which results in fish kills, toxicity of drinking water, and a decrease in water aesthetics. Production agriculture accounts for 66% and 65% of total national P and N discharges, respectively (Stephen et al., 1997). The major concern for groundwater pollution is NO_3-N leaching, whereas the major concern for surface water pollution is the eutrophication of lakes from excess P.

The application of animal manure to agricultural lands is a favorable alternative source of nutrients to commercial fertilizer because manure is less expensive, increases soil organic matter content, and allows for the disposal of organic wastes. Few reports on the effects of long-term application of animal manure conclude that manure may influence soil productivity and prevent soil degradation. The immediate impact of manure applications on agricultural land includes increases in dissolved organic and inorganic substances in the soil, which may also be potential sources of pollutants in groundwater (Goodman, 1991). Water quality results from 'The Iowa State-Wide Rural Well Water Survey' (1993) showed that about 11% of the wells tested had both NO_3-N levels greater than 10 mg l^{-1} and positive tests for fecal and total coliforms bacteria.

With greater application rates of manure nutrients, the potential for water contamination has increased significantly. Manure application rate is influenced by the animal unit to land ratio. Letson and Gollehon (1996) discuss the matter that many large specialized facilities lack substantial land resources for application of such large quantities of manure produced. Nationally, about 27% of the swine produced are raised on large farms that have only 3% of the land available for manure application. Since 1974, the number of producers in the United States has decreased from 750,000 to 157,000 (Thu, 1998). Between 1994 and 1996, 25% of all hog producers in the United States stopped raising livestock. By the end of 1996, 3% of the producers in the United States produced 51% of all hogs marketed (Thu, 1998), and in 1998 1.7% of the producers raised 47% of all hogs marketed (Iowa Agricultural Statistics, 1998).

Iowa leads the nation in hog production with an estimated 14.5 million hogs on-hand in December 1997. This represents about 22% of the total numbers of hogs and pigs produced in the United States. During the past several years, livestock production in Iowa has become more concentrated and intense. According to the USDA between 1987 and 1997 the number of farms in Iowa raising hogs declined from 36,670 in 1987 to 31,790 in 1997 (a 13% decrease), but the number of livestock increased from 12,983,074 to 14,500,158 (a 12% increase). During the same period, the size of farms increased from 301 acres to 339 acres from 1987 to 1997. In 1997, Iowa was the leading hog producing state in the United States, followed by North Carolina (9,800,000 hogs) and Minnesota (5,500,000 hogs). The value of the hogs on farms in Iowa in 1997 was $1,233 million. The 1996 cash receipt from hog production in Iowa was estimated at $3,004 million. While the corresponding 1995 cash receipt was calculated at $2,550 million. Without a doubt, livestock production is an integral part of Iowa's economy and the economy of many Midwestern and Southeastern states.

A number of studies have been conducted to elucidate the relationship between livestock production and environmental quality. Stone et al. (1998) investigated the potential implications of a large swine production facility in North Carolina on water quality. When a swine farm in the Herrings Marsh Run Watershed increased its operation from 3,300 to 14,000 animals, they found that NO_3-N concentrations increased significantly in three of seven wells located adjacent to the livestock operation. Furthermore, NO_3-N concentrations increased in the winter months, but remained consistent with concentrations detected before the expansion of the livestock operation during the summer.

Another environmental quality issue associated with livestock production is air pollution from livestock facilities is atmospheric pollution in the form of odor. Air pollution can be defined as the presence of contaminants in air under conditions that are injurious to humans, plants, and animal life, or which unreasonably interferes with the quality of life (Loehr, 1974). Odors associated with livestock production can be traced to (i) manure storage structures, (ii) land application of manure, and (iii) ventilation exhaust from livestock buildings. Recent odor complaints in Iowa have been directed more at manure storage structures than to any other sources (Melvin, 1995). Odors from manure are associated with the decomposition of proteinaceous waste products, such as urine, skin, hair, and spilled or spoiled feed (O'Neill and Philip, 1991). Odorous substances in animal wastewater can be classified as either organic vapors or inorganic vapors (Dague, 1972). Inorganic gases produced from manure include: hydrogen sulfide (H_2S), ammonia (NH_3), carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2), oxygen (O_2), and hydrogen (H_2). Organic gases are produced during anaerobic decomposition of compounds containing nitrogen and sulfur (Dague, 1972).

Across the United States, there are a variety of approaches designed to protect residences from livestock odor. These approaches are diverse and include agricultural zoning by counties, property line odor intensity limits, objectionability criteria, nuisance-free continuation rights, and establishment of separation distances between residences and livestock production sites. Iowa has established setback distances for buildings, depending on land use and the total body weight of pigs (starting at 200,000 lb) (Kohl and Lorimor, 1997). For instance, in incorporated areas, the setback distances increases from 375 m for 90,719 kg to 750 m for 566,991 kg or more. For unincorporated areas, these distances are 225, to 450 m for 90,719 and 566,991 kg, respectively.

Van Kleeck and Bulley (1992) conducted a survey of neighbors around seven, 100- to 225-sow farrow-to-finish operations to assess the relationship between the perception of odor nuisance, separation distance, and the size of the facility. The frequency of neighbors that identify swine farms as a nuisance was inversely proportional to the square of the separation distance. About 20% of neighbors living approximately 660 m away from swine farms perceived them to be a nuisance. Farm size apparently had no effect between 180 and 360 m.

Atmospheric dispersion modeling offers an alternative approach to evaluating the potential for odor nuisance complaints from livestock facilities. In particular, the Gaussian plume model such as developed by Bowers et al. (1979) and Lorimor (1986) has been widely used to predict the dispersion of odorous pollutants from livestock facilities and manure application areas. For example, Janni (1982) used a simple point source to evaluate the importance of the model parameters. Carney and Dodd (1989) compared measured and predicted odors from point, line and areal sources. Smith (1993) developed STINK, a computer program to calculate the normalized concentration downwind of a rectangular source. Chen et al. (1998) proposed a new mathematical model for the dispersion parameters in the Gaussian plume model to better simulate odor dispersion.

Analysis of impacts of livestock production and manure application on environmental quality has also required the use of biophysical models of agricultural non-point source pollution. These models provide the analytical tool for quantifying the effects of both point and non-point source pollution on water quality (Nix, 1994; Presti and Lubello, 1993; Donigian and Huber, 1991). In addition, the result from these models can assess potential consequences of alternative management scenario or policy-level decisions; and can also be a cost-effective and efficient substitute to long-term monitoring of fields, watersheds, and basins (Heng and Nikolaidus, 1998).

During the past two decades, a number of biophysical models have been developed to facilitate analyses of non-point source pollution from crop and livestock production. These models include: the Universal Soil Loss Equation (USLE) (USDA 1992), SCS curve number methods (USDA 1972), EPIC or Erosion Productivity Impact CAlculator (Williams et al. 1984); CREAMS or Chemicals, Runoff and Erosion from Agricultural Management Systems (Knisel, 1980); WEPP or Water Erosion Prediction Process (Foster and Lane 1987); ANSWERS or Areal Nonpoint Source Watershed Environmental Response Simulation (Beasley et al.); AGNPS or Agricultural Non-point Source Pollution Model (Young et al. 1989); SWRRB-WQ or Simulator for Water Resource Rural Basin - Water Quality (Arnold et al., 1990); and SWAT or Soil and Water Assessment Tool (Arnold et al., 1996).

A number of studies have used these models to assess soil and water quality impacts on agricultural production. For example, Srinivasan et al. (1993) applied the SWAT model to the Seguin and Naches River Basins in Texas. They reported Nash-Sutcliffe (R^2) values of 0.86 and 0.82 between simulated and observed monthly flow for the two basins, respectively. Srinivasan and Arnold (1994) used SWAT to model the Seco Cheek watershed in Texas, where 98% of the watershed is being used as rangeland, and reported that average monthly predicted flows were 12 percent lower than measured flows. Binger (1996) also reported reasonably close agreement between measured and simulated annual volumes within 90% for most subbasins by using SWAT.

Peterson and Hamlett (1998) calibrated the hydrologic component of SWAT model for the Ariel Watershed in Pennsylvania that contains soils with fragipans. Rosenthal et al. (1995) used SWAT to evaluate water yields from the Lower Colorado River Basin in Texas. Measured outflow from an upstream reservoir was used as initial input to the model. Binger et al. (1997) evaluated sub-watershed size dependency of the SWAT model on simulated annual runoff and sediment yield of fine sediments. Manguerra and Engel (1998) described the important parameterization issues involved when modeling watershed hydrology for runoff prediction using SWAT. Galichand et al. (1998) assessed the effects of best management practices (BMPs) on a watershed in Quebec. BMPs were established one year after a water quality monitoring program was initiated for the watershed. The BMPs implemented included timing of fertilizer application, geographic distribution of animal waste application, and a method of manure application. Their study also concluded that in order to balance manure P applications, exporting manure or reducing livestock population in the watershed was required since P levels in fields were exceedingly high.

Study Objectives

From the preceding discussions, it is evident that growth in the livestock industry in Iowa and many other states and the corresponding manure production have contributed to concerns for environmental quality. With the projected trend in increased concentration of livestock production systems and the need to resolve the conflict between livestock producers and the community, new tools and decision support systems must be developed. These tools provide the framework for evaluating the potential air, soil, and water quality impacts of livestock production practices. They can be used quite effectively as an environment for consensus building allowing resource managers, livestock producers, and grass-roots community groups to work together to plan and implement production practices that are equitable, sustainable, and contribute to a sustainable livestock production industry. The overall goal of this research is to address the environmental quality issues associated with livestock production through development and application of a DSS that facilitates analysis and management of sustainable livestock production enterprises. The specific objectives are to:

1. Develop a GIS-based site selection system for identifying environmentally sensitive and suitable land areas for siting livestock operations and for land application of animal manure.

2. Develop a DSS for evaluating the environmental and social impacts of livestock production practices and land application of animal waste.

3. Determine the effectiveness of alternative cropping systems and manure management practices in reducing adverse effects of livestock production on soil, air, and water resources.

Thesis Organization

The organization of this thesis follows a journal article format. It consists of five chapters organized as follows: Chapter 1 serves as an introduction to the research and provides a comprehensive literature review of the problem and a method of solution. This is followed by three chapters written in a format suitable for publication in refereed journals. The first paper (Chapter 2) entitled "A Decision Support System for Planning Sustainable Livestock Production Systems" is to be submitted to the Journal of Soil and Water Conservation. The second paper (Chapter 3) entitled "Simulating Odor Dispersion from Livestock Facilities using GIS " is to be submitted to the Journal of Environmental Quality. The third paper (Chapter 4) entitled "Evaluating Water Quality Impacts of Livestock Production Practices" is written for submission to the Journal of Soil and Water Conservation. Each paper contains an abstract, introduction, material and methods, results, discussion, conclusion, and references. Chapter 5, a general conclusion of the study, follows these papers.

References

Arentze, T.A. A.W.J. Borgers, and H.J.P. Timmermans. 1996. Design of a View-Based DSS for Location Planning. International Journal of Geographical Information Systems 10:219-236.

Armstrong, M.P. G. Rushton, R. Hoeney, B.T. Dalziel, P. Loolonis, S. De. and P.J. Densham. 1991. Decision Support System for Regionalization: A Spatial Decision Support System for Regionalizing Service Delivery Systems. Computer Environ. and Urban Systems 15:37-53.

Arnold, J.G. J.R. Williams, A.D. Nicks, and N.B. Sammons. 1990. SWRRB: A Basin Scale Simulation Model for Soil and Water Resources Management. College Station, Texas: Texas A&M University Press

Arnold, J.G., J.R. Williams, R. Srinivasan, K.W. King. 1996. SWAT – Soil and Water Assessment Tool. USDA Agricultural Research Service, Temple, Texas: Blackland Research Center, Texas A&M Agriculture Experiment Station.

Basagoglu, H., E. Celenk, M.A. Marino, and N. Usul. 1997. Selection of Waste Disposal Sites using GIS. Journal of American Water Resources Association 3:455-464.

Beasley, D. B. L. F. Huggins and E.J. Monke. 1980. ANSWERS: A Model For Watershed Planning. Transactions of the ASAE 23:938-44.

Binger, R. L., J. Garbrecht, J. G. Arnold, and R. Srinivasan. 1997. Effect of Watershed Subdivision on Simulation Runoff and Fine Sediment Yield. Transaction of the ASAE 40:1329-1335.

Binger, R.L. 1996. Runoff Simulated from Goodwin Creek Watershed using SWAT. Transactions of the ASAE 39:85-90.

Bowers, J.F., J.R. Bjorkland, and C.S. Cheney. 1979. Industrial Source Complex (ISC) Dispersion Model User's Guide Report EPA-450/4-79-030. Washington, D.C.: US Environmental Protection Agency.

Brooks, C. J. 1997. A Parameterized Region-Growing Programme for Site Allocation on Raster Suitability Maps. International Journal of Geographic Information Science 11:375-396.

Burrough, P.A. 1986. Geographical Information Systems for Land Resource Assessment. Oxford: Clarendon Press.

Carney, P.G. and V.A. Dodd. 1989. A Comparison Between Predicted and Measured Values for the Dispersion of Malodours from Slurry. Journal of Agricultural Engineering Research 44:67-76.

Chen, Y.C., S.J. Hoff, and D.S. Bundy. 1998. Modeling and Evaluation of Dispersion Parameters For Odors From Agricultural Sources. Journal of Environmental Systems 26:27-39.

Cox, C. and C. Madramootoo. 1998. Application of Geographic Information Systems in Watershed Management Planning in Saint Lucia. Computers and Electronics in Agriculture 20:229-250.

Cruz, G.I. 1993. Determining Sites for Solid Waste using GIS. pp. 363-367. In: Proceedings of the Thirteenth Annual ESRI User Conference, Redlands, California. Environmental Systems Research Institute.

Dague, R. R. 1972. Fundamentals of Odor Control. Journal of Water Pollution Control Federation 44:583-594.

Densham, P.J. 1991. Spatial Decision Support Systems. pp. 403-412. In Geographical Information Systems: Principles. Edited by D.J. Maguire, M.F. Goodchild, and D.W. Rhind. New York, New York: Springer Verlag.

Donigian, A. S. and W. C. Huber. 1991. Modeling of Nonpoint Source Water Quality in Urban and Non-Urban Areas. EPA/600/3-91/039. Athens, Georgia: Environmental Protection Agency.

Foster, G.R. and L.J. Lane. 1987. User Requirements USDA Water Erosion Prediction Project (WEPP). INSERL Report No. 1, National Soil Erosion Research Laboratory. West Lafayette, IN: Purdue University.

Galichand, J., E. Aubin, P. Baril, and G. Debailleul. 1998. Water Quality Improvement at the Watershed Scale in an Animal Production Area. Journal of the CSAE 40:67-78.

Gar-On Yeh, A. and X. Li. 1998. Sustainable Land Development Model for Rapid Growth Areas using GIS. International Journal of Geographical Information Science 2:169-189.

Goodchild, M.F., B.O. Parks, and L.T. Steyaert (eds.). 1993. Environmental Modeling with GIS. New York, New York: Oxford University Press

Goodrich, J.A., B.W. Lykins Jr., and R.M. Clark. 1991. Drinking Water from Agriculturally Contaminated Ground Water. Journal of Environmental Quality 20:707-717.

Grimshaw, D.G. 1994. Bringing Geographical Information Systems into Business. Essex, England: Longman Scientific and Technical.

Hendrix, W.G. and D.J.A. Buckley. 1992. Use of a Geographic Information System for Selection of Sites for Land Application of Sewage Waste. Journal of Soil and Water Conservation 47:271-275.

Heng, H.H. and N.P. Nikolaidus. 1998. Modeling of Nonpoint Source Pollution of Nitrogen at the Watershed Scale. Journal of American Water Resources Association 34:359-374.

Hynes, H. B. N. 1971. The Biology of Polluted Waters. Toronto, Canada: University of Toronto Press.

Iowa Agricultural Statistics. 1998. 1998 Iowa Agricultural Statistics. J.K. Sands and Holden (Editors). U.S. Department of Agriculture and Iowa Farm Bureau: Des Moines.

Jain, D.K., U.S. Tim and R. Jolly. 1995. Spatial Decision Support System for Planning Sustainable Livestock Production. Computer, Environmental, and Urban Systems 19(1): 57-75.

Janni, K.A. 1982. Modeling Dispersion of Odorous Gases from Agricultural Sources. Transactions of the ASAE 25:1721-1723.

Kelly, M. E. 1996. Fears about Waste Lagoons Seen Spurring Calls for Crackdown. Des Moines Register. September 21:3A.

Klausner, S. D., A. C. Mathers, A. L. Sutton. 1991. Managing Animal Manure as a Source of Plant Nutrients. National Corn Handbook, NCH-12. Ames, Iowa: Iowa State University Extension.

Knisel, W.G., ed. 1980. CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. USDA, Conservation Research Report No. 26. Washington D.C.: U.S. Department of Agriculture.

Kohl, K. and J. Lorimor. 1997. Swine Manure Management and Iowa's Manure Law. Engineering, 1-1. Ames, Iowa: Iowa State University Extension.

Lane, L.J., J.C. Ascough, and T.E. Hakonson. 1991. Multi-objective Decision Theory – Decision Support System with Embedded Simulation Models. In Proceedings of: Irrigation and Drainage IR Division, ASCE. Editor W.F. Ritter. ASCE, New York, New York.

Lasley, P. 1995. Iowa Farm and Rural Life Pool. Summary Report. Pm-1628:14. Ames, Iowa: Iowa State University Extension.

Letson, D. and N. Gollehon. 1996. Confined Animal Production and the Manure Problem. Choices. 11:18-21,24.

Leung, Y. 1997. Intelligent Spatial Decision Support Systems. Springer-Verlag, Berlin, Germany.

Loehr, R. C. 1974. Agricultural Waste Management: Problems, Processes, and Approaches. New York, NY: Academic Press, New York.

Lorimor, G. 1986. The AUSPLUME Gaussian Plume Dispersion Model. Contract EPS/86-02, Melbourne, Victoria, Australia: Environmental Protection Authority.

Manguerra, H.B. and B.A. Engel. 1998. Hydrologic Parameterization of Watershed for Runoff Prediction using SWAT. Journal of American Water Resources Association 34: 1149-1162.

McMillen, M.D. and D.R. Gorman. 1993. Nowhere to Hide. Water Environment and Technology. 5:36-42.

Melvin, S. W. 1995. Manure Storage. In: Proceedings of the International Livestock Odor Conference. 1995. October 16-18, 1995. Ames, Iowa: Iowa State University.

Mertz, T. 1993. GIS Targets Agricultural Nonpoint Pollution. GIS World. 6:41-46.

Newell, C.J. H.S. Rifai, and P.B. Bedient. 1992. Characterization of Non-Point Sources and Loading to Galveston Bay. Publication GBNEP-15, Galveston, Texas: The Galveston Bay National Estuary Program.

O'Neill, D. H. and V. R. Phillips. 1991. A Review of the Control of Odour Nuisance from Livestock Buildings: Part 1, Influence of the Techniques for Managing Waste within the Building. Agricultural Engineering Research 50:1-10.

Peterson, J.R. and J.M. Hamlett. 1998. Hydrologic Calibration of the SWAT Model in a Watershed Containing Fragipan Soils. Journal of American Water Resources Association 34:531-544.

Presti, F. and C. Lubello. 1993. The Distributed Modeling of Agricultural Nonpoint Pollution at a Basin Scale: Experimental Research and Model Validation. Water Science Technology 28:669-674.

Puckett, L. J. 1995. Identifying the Major Sources of Nutrient Water Pollution. Environmental Science Technology 29:408-414.

Quinlan, B. and C. Simmons. 1993. Exploring Land Use Alternatives. Water Environment and Technology 3:44-50.

Rabalais, N.W. W.J. Wiserman, R.E. Turner, B.K. Sen Gupta, and Q. Dortch. 1996. Nutrient Changes in the Mississippi River and System Responses on the Adjacent Continental Shelf. Estuaries 19:386-407.

Rewerts, C.C. and B.A. Engel. 1991. ANSWERS on GRASS: Integrating a Watershed Simulation with a GIS. ASAE Paper No. 91-2621. St. Joseph, Michigan: American Society of Agricultural Engineering.

Rosenthal, W.D., R. Srinivasan, J.G. Arnold. 1995. Alternative River Management Using a Linked GIS-Hydrology Model. Transactions of the ASAE 38: 738-790.

Smith, E. O., C. W. Lindwell, M. Green, and C. K. Pavlik. 1997. PARMS: A DSS for Planting and Residue Management. Computers and Electronics in Agriculture 16:219-229.

Smith, R. J. 1993. Dispersion of Odours from Ground Level Agricultural Sources. Journal of Agricultural Engineering 54:187-200.

Sprague, R.H. and E.D. Carlson. 1982. Building Effective Decision Support Systems. Prentice Hall, Englewood Cliffs, New Jersey.

Srinivasan, R. and B.A. Engel. 1994. A Spatial Decision Support System for Assessing Agricultural Nonpoint Source Pollution. Water Resources Bulletin 30: 441-452.

Srinivasan, R., T.S. Ramanarayanan, R. Jayakrishnan, H. Wang. 1997. Hydrologic Modeling of Rio Grande/Rio Bravo Basin. Paper No. 972236. St. Joseph, MI: American Society of Agricultural Engineers.

Srinivasan, R. and J.G. Arnold. 1994. Integration of a Basin Scale Water Quality Model with GIS. Water Resources Bulletin 30: 453-462.

Stephen, B.L, J. Glee, T. O. Randhir, and B. A. Engel. 1997. Research Needs for Water Quality Management in the 21st Century: A Spatial Decision Support System. Journal of Soil and Water Conservation 52:18-25.

Stone, K. C. P. G. Hunt, F. J. Humenik, and M. H. Johnson. 1998. Impact of Swine Waste Application of Ground and Stream Water Quality in an Eastern Coastal Plain Watershed. Transactions of the ASAE 41:1165-1670.

Thu, K. M. 1998. Rural Health and Large-Scale Swine Operations. pp. 321-324. Manure Management 1998. Ames, Iowa: Soil and Water Conservation Society.

U.S. Department of Energy. 1986. Area Recommendation Report for the Crystalline Repository Project. Vol 1, Draft Report, NTIS No. DE87012337/GAR, Crystalline Repository Project Office, Argon, Illinois.

U.S. Environmental Protection Agency. 1997. National Water Quality Inventory: 1996 Report to Congress (EPA 841-R-97-008). Washington, D.C.: Office of Water, U.S. Environmental Protection Agency.

Van Kleeck, R.J. and N.R. Bulley. 1992. An Assessment of Separation Distance as a Tool for Reducing Farm/Neighbor Conflict. Odour Prevention and Control of Organic Sludge and Livestock Farming. V.C. Nielsen, J.H. Voorburg, P. L'Hermite (Editors). New York, NY: Elsevier Applied Science Publishers.

Wang, X. 1997. Application of Computer Program to Localization of Vegetable Production in Hangzhou. pp. 652-658. In: Computers in Agricultural Extension Programs. D. G. Watson, F. S. Zazueta, and A. B. Batcher. St. Joseph, Michigan: American Society of Agricultural Engineers.

Williams, J. R. C. A. Jones, and P. T. Dyke. 1984. A Modeling Approach to Determine the Relationship Between Erosion and Soil Productivity. Transactions of the ASAE 27:129-44

Wolfe, M.L. and P.N. Delman. 1990. Optimizing Dairy Site Selection Using a Geographic Information System. In Proceedings: Application of Geographic Application Systems, Simulation Model, Knowledge-based Systems for Landuse Management. November 12-14, 1990. Department of Agricultural Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Yakowitz, D.S. L.J. Lane, and F. Szidarovsky. 1993. Multi-Attribute Decision-Making Dominance with Respect to and Importance Order of the Attributes. Applications of Mathematical Computation 54:167-181.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1989. AGNPS. A Nonpoint Source Pollution Model for Evaluating Agricultural Watersheds. Journal of Soil and Water Conservation 44:168-173.

CHAPTER 2. A DECISION SUPPORT SYSTEM FOR PLANNING SUSTAINABLE LIVESTOCK PRODUCTION SYSTEMS

A paper to be submitted to the Journal of Soil and Water Conservation

Crawford, I.M. and U.S. Tim

Abstract

Three primary environmental concerns related to agricultural production include: water pollution from livestock facilities, soil and water contamination from fertilizer and manure application, and air pollution from animal production facilities and land application sites. To minimize the potential environmental problems associated with livestock production, there is a need for analytical tools and decision support systems (DSS) that can be used to identify optimal land areas both for siting production facilities and for manure application, and for evaluating the impacts of management practices on air, soil, and water quality. This paper describes the details of LPRDSS (Livestock PRoduction Decision Support System), a DSS developed for the planning of livestock production enterprises and also for evaluating air and water quality pollution from production practices at the watershed and county levels. LPRDSS integrates environmental, physical, and regulatory factors, agricultural database, and GIS into a computer-aided DSS designed to assist decision makers in making rational choices in planning sustainable livestock enterprises that minimize environmental pollution. An example application to Taylor County in southern Iowa demonstrates the use and capability of LPRDSS as an effective management tool.

Introduction

During the past decade, Iowa has seen tremendous growth in livestock production. In 1987, 36,670 farms produced 13 million hogs and pigs, and by 1997 there were 31,790 farms producing 14.5 million hogs and pigs (Iowa Agricultural Statistics, 1998). This increase in the size of production systems is also seen nationally. In 1994, for example, there were thirty-one swine farms across the United States that contained at least 10,000 sows and by 1997 there were fifty-four facilities with greater than 10,000 sows (Freese, 1995, 1997). As the size of livestock facilities increase so do the concerns for environmental quality and public health. Agricultural production, including livestock and crops, has been cited as the major source of non-point source pollution of lakes, rivers and estuaries (EPA, 1997). According to the EPA report nearly 40% of the assessed surface waterbodies in the United States are too polluted for basic uses, such as fishing and swimming. Furthermore, the report concludes the impairment to water resources is caused primarily by nutrients than by any other single pollutant. Excessive application and improper utilization of animal manure can lead to undesirable effects on surface and ground water resources. Runoff from poorly sited facilities and manure application sites, manure storage lagoons that leak, and improperly timed manure applications can contribute to adverse impacts on surface and groundwater. Manure contains considerable amounts of nitrogen, phosphorus, potassium and other minerals. Any amount of these nutrients not utilized by the plant remains attached to soil particles or are carried by runoff water to streams, lakes and rivers. In addition, other soluble nutrients, such as nitrate-nitrogen, may leach through the soil and contaminate groundwater in addition to surface water pollution.

Ground water pollution from nitrates present significant health threats. A 1992 report by the U.S. Environmental Protection Agency concluded that 4.5 million people are being served by water systems that exceed the maximum contaminant level. Ground water is the major source of drinking water for more than 90% of rural households and 75% of cities in the U.S. (Goodrich et al., 1991). When ingested, nitrates present in drinking water can be converted to nitrites. In turn, nitrite can interfere with the oxygen-carrying capacity of red blood cells and produce a condition known as methemoglobinemia or "blue baby syndrome" in infants. In addition to health concerns, Hynes (1971) noted that high nutrient overloading of nitrogen and phosphorus in surface water can lead to an increase in plankton, algae, and ultimately to eutrophication of surface waters and fish kills. Also, manure spills from lagoons directly into waters can lead to fish kills. In 1996, forty animal waste spills killed 670,000 fishes in Iowa, Minnesota, and Missouri (USDA, 1997).

Large non-farm populations (urban sprawl) and rapidly expanding hog operations have also led to new concerns over air quality. Odors from swine facilities are caused primarily by decomposing manure, rotting feed, dust emissions, incineration of dead pigs and unprocessed carcasses (Heber, 1997). These emissions contribute to local odor nuisance complaints and to regional air quality issues. The 1995 Iowa Farm and Rural Life Poll found that 57 of the 1380 livestock producers questioned reported they had received complaints about odors, noise, or flies from their neighbors. Odor nuisance suits have increased in the past decade with the number and size of production facilities. Nuisance suits arise because neighbors complain that odors from animal production affects the quality of their lives, cause yet unknown long-term health problems, and reduce real estate property values. In response, many states have passed setback ordinances for livestock facilities as an attempt to reduce nuisance lawsuits. For example, Iowa has established setback distances between large hog operations and neighbors, depending on land use and the total body weights of pigs (Kohl and Lorimor, 1997). For incorporated areas, established distances range from 380 m to 562 m for 90,719 kg and 283,495 kg animal live weight, respectively. For unincorporated areas, the corresponding setback distances are 225, 300, and 450 m for 90,719, 283,495, and 566,991 kg animal live weight, respectively. The number, type, and weight of hogs and pigs produced at a facility; building design; techniques for manure handling, treatment, storage, and disposal; and odor control technologies significantly influence odors emitted from a livestock production facility. Other meteorological factors such as weather patterns, air temperature, solar insulation, relative humidity, and particulate concentration also influence transport and concentration of livestock odor.

Proper site planning for livestock production and manure disposal can reduce the impact of livestock production on environmental quality. However, there is a need for analytical tools and DSS to guide the producer and decision-maker in identifying livestock production sites and manure management practices that are environmentally sound and socially acceptable. In the past, emphasis has been placed on modeling the impacts of a production decision (e.g. siting of a facility or manure application) after the environmental degradation has occurred. The analytical tool and DSS described in this paper is called the Livestock PRoduction Decision Support System (or LPRDSS) and is designed to facilitate the selection of an optimal land area either for siting a facility or for manure application, and to also enhance the prediction of the potentially adverse environmental impacts of production system practices. LPRDSS is an interactive microcomputer-based system uniquely designed to facilitate evaluation of alternative site selection options, to incorporate different management objectives and criteria, and to enhance the use of biophysical models in characterizing the associated air, soil, and water quality impacts. Overall, LPRDSS consists of different biophysical models including: a multi-objective site evaluation model, a water quality model, and an odor dispersion model. These models are linked with the ArcView GIS. Figure 1 describes the schematics of the LPRDSS.

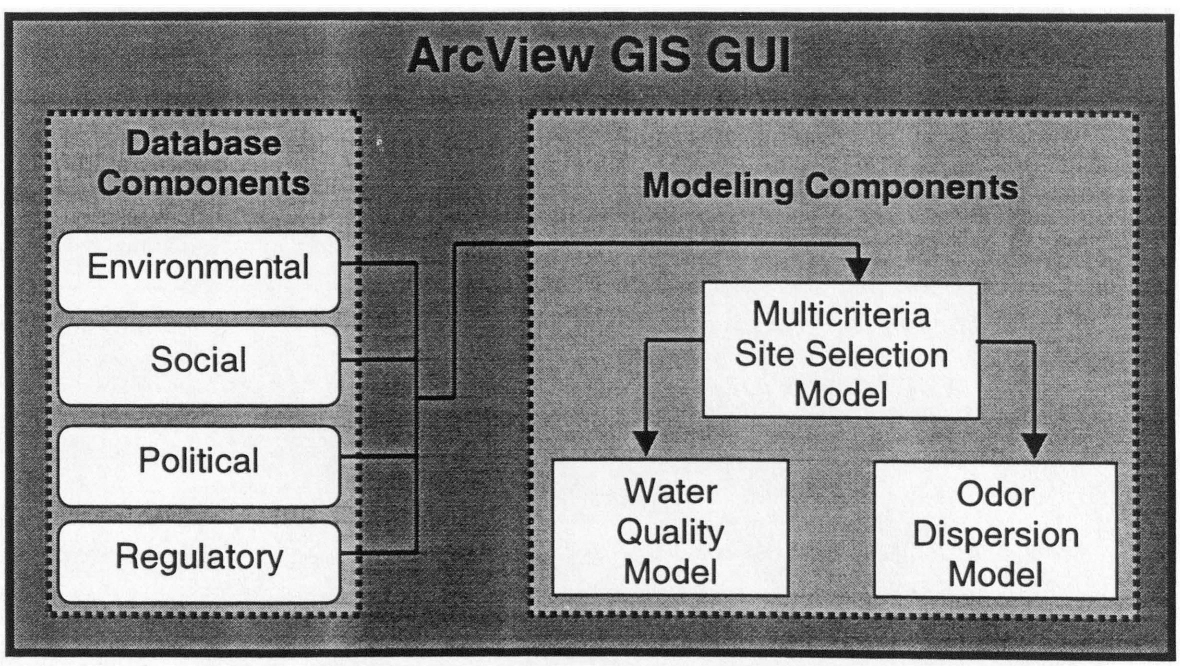

Figure 1. Components of the Livestock PRoduction Decision Support System (LPRDSS).

Although it is generally recommended to make management decisions affecting water quality on a watershed level, such decisions are still made either on a county, state, or federal level. The LPRDSS allows the decision-maker to choose optimal sites for facilities or land areas for manure application on any user-defined management scale, including a county basis but allows watershed-level evaluation of water quality impacts of the site selection and manure application options. Furthermore, users of LPRDSS can examine the potential air quality impacts of each planning option at the county or watershed scale. The scale with which LPRDSS is used depends on the availability of the data required by the site selection model and the biophysical model. The following objectives were established during the development of LPRDSS. The system should allow users to: (1) determine socially acceptable and environmentally sound land areas for siting livestock facilities and applying manure at different management and spatial scales; (2) evaluate the impacts to fragile ecosystems and resources from manure application; (3) identify the social implications of a particular livestock facility in terms of its contribution to odor nuisance complaints from neighbors; and (4) be convenient to input data and visualize and interpret results of the siting options as well run on a standard desktop computer with a satisfactory speed of operation.

ROLE OF GIS

GIS, a tool that facilitates the collection, storage, management, analysis, and display of spatially referenced data (Burrough, 1986), has been used quite extensively in many disciplines and application areas. Recently, many studies have integrated GIS with models, expert systems, and statistical analysis software packages to increase its functionality and applicability. Integrating databases and models with GIS provides a reasonable framework for developing an effective and efficient DSS for the planning of environmental protection programs. One advantage of integrating models with GIS is that the modeling environment can be adapted to a wide range of spatial and temporal conditions that represent the nature of the application. A GIS facilitates manipulation and display of large volumes of previously unconnected datasets, bringing them into a common reference system for spatial analysis and modeling from which decisions can be made (Joao and Walsh, 1992). During the past decade, many attempts have been made to develop GIS-based DSS for environmental and natural resource management (Wolfe et al., 1990; Hendrix et al., 1992; Jain et al, 1995; and Gar-On Yeh and Li, 1998)

In this research, the functionality of GIS was combined by several models to develop LPRDSS. The roles of GIS in LPRDSS are to store and manage the spatial database related to livestock production and environmental quality, and to perform spatial analysis (i.e. overlays and buffering) on various landscape and environmental variables that influence the locations of livestock facilities, as well as the land areas for manure application. In addition, the GIS also serves as an effective screening tool in the site selection process, allowing the decision-maker to narrow the number of candidate sites and to identify optimal sites for detailed investigation. The GIS graphical user interface (GUI) allows users to efficiently manipulate large quantities of spatial data. The main GUI of LPRDSS as shown in Figure 2, enables users to submit the basic set of input data to the DSS through interactive buttons, menu choices, and dialog boxes. It also allows users to view the results of the analysis to gain new insights into the decision-making process or improve their understanding of the problem being solved. In many environmental management applications, GIS visualization and data presentation are used extensively to communicate complex and dynamic nature of land surface processes. Within the GIS user community, there is growing interest in spatial modeling environments that are visual and also support multiple and simultaneous representations of the problem or the solution set. Through visualization, users can perform informal queries about the conditions of the natural environment or visualize the impacts of management decisions.

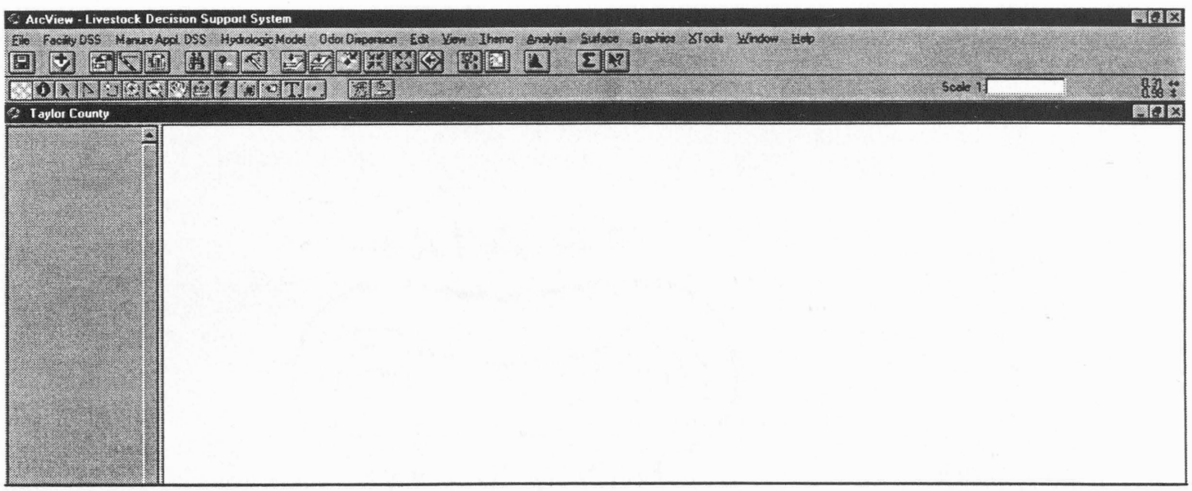

Figure 2. Main interface for the LPRDSS

In LPRDSS, the GUI is provided by ArcView GIS (ver 3.1) developed by the Environmental Systems Research Institute (ESRI) at Redlands, California. ArcView was chosen as the development platform for several reasons, including: (1) a user-friendly, menu-driven interface; (2) its use of both the raster and vector data structures for manipulation of geographic features and feature attributes; and (3) ability to operate on a standard desktop computer with reasonable speed and consistency. One desirable feature in ArcView is its ability to manage, manipulate, and modify existing GIS coverages. In addition to ArcView's base program, the addition of the Extension features (Spatial Analyst, 3-D Analyst, etc.) provides new power and flexibility to analyze spatially distributed data. For example, the ArcView Spatial Analyst Extension provides the ability to create, overlay, query, and analyze multiple raster data, while ArcView's object-oriented programming language, Avenue, can be used to customize the user interface, enhance the coupling of models with the GIS database, and build custom tools and dialog boxes for improved "human-computer interaction". The ArcView's 3D

Analyst Extension enables users to create, analyze, and display surface data and to convert static 2-D maps into dynamic, interactive, 3-D displays for improved understanding of spatial relationships within the information.

Multi-Objective Site Evaluation Model

The multi-objective site evaluation model follows the methodology described by Jain et al. (1995). The model consists of a spatial weighting scheme of 14 different environmental, social, political, and regulatory variables that influence livestock facility siting as well as land areas to apply manure. Representing these variables are a set of site selection criteria, including: distance from streams, roads, lakes, wetlands, and wells (agricultural drainage and drinking); proximity to residences, sinkholes, incorporated and other public areas, and landmarks such as churches and schools; topographic features and physical characteristics, such as land slope and aspect; and environmental factors such as soil drainage, soil permeability, flood potential, and land cover. Each variable is subdivided into categories based on regulatory and/or scientific criteria, and each criterion is subsequently assigned a weight based on its suitability. Table 1 lists some of the variables, criteria, and criteria ratings used in LPRDSS for siting livestock facilities.

Table 1. Summary of some criteria ratings important to siting a livestock production facility.

Soil Drainage		Land Slope		Public Areas/Towns	
Category	Rating	Category	Rating	Category	Rating
Well Drained	10	0%-2%	10	< 420 m	0
SW Mod Well Dr.	9	2%-5%	8	420 – 500 m	2
Mod. Well Drained	7	5%-14%	6	500 –600 m	6
SW Poorly Drained	3	14%-35%	2	600 – 800 m	9
Poorly Drained	0	>35%	0	> 800 m	10
Soil Permeability		**Lakes/Wetlands/Stream**		**Road Proximity**	
Category	Rating	Category	Rating	Category	Rating
< 0.15 cm/hr	0	< 60 m	0	< 210 m	0
0.15 – 0.51 cm/hr	2	60 – 100 m	2	210 m – 402 m	6
0.51 – 1.52 cm/hr	4	100 – 200 m	6	402 m – 804 m	10
1.52 – 5.10 cm/hr	8	200 – 300 m	8	804 m – 1609 m	9
5.10 – 15.2 cm/hr	9	300 – 400 m	9	1609 m – 3218 m	6
> 15.2 cm/hr	10	> 400 m	10	> 3218	0
Agricultural and Drinking Wells		**Flood Frequency**		**Land Cover and Land Use**	
Category	Rating	Category	Rating	Category	Rating
< 160 m	0	Frequent	0	Urban, Industrial,	
160 – 200 m	2	Common	2	Commercial,	0
200 – 300 m	6	Occasional	7	Forest, & Water	
300 – 400 m	8	Rare	9	Other (row crops)	10
> 400 m	9	None	10		

The multi-objective site evaluation model is implemented either as an exclusive (or absolute) criteria that eliminates sites from consideration on the basis of environmental, social, or political regulatory restrictions or as a non-exclusionary (or relative) criteria that ranks suitable land units according to their relative ranking computed by a scaled composite suitability score. In the absolute criteria, a site is automatically eliminated if it fails to meet a specified criterion for each regulatory or physiographic restriction such as slope, distance to streams, and soil drainage. In the relative ranking option, each criterion is ranked using an appropriate rating scheme. For example, the proximity to stream criteria is divided into six categories based on numerical values of distances, and a factor score or rating is then assigned to each category. A site having a distance greater than 400 m from a stream receives an appropriately higher rating than a site that is only 100 m from the stream. A weight is then assigned to represent the importance of stream proximity to the overall suitability of the site. The suitability or desirability of a site or land unit *i* for a given criterion *j* can be determined by using the following equation:

$$S_{ij} = \sum_{j=1}^{N} f_{ij} w_j \tag{1}$$

in which:

$$f_{ij} = \begin{bmatrix} f_{i1} \cdots\cdots f_{iN} \\ . \quad . \quad . \quad . \\ f_{1j} \cdots\cdots f_{ij} \end{bmatrix} \tag{2}$$

$$\Sigma w_j = w_i + w_2 + w_3 ... + w_j \tag{3}$$

where S_{ij} is the composite suitability score of the land unit, f_j ($0 \leq f_j \leq 10$) is the factor score, or rating, or numerical score of a variable, w_j (<100) is the assigned weight of the criterion, and *N* is the number of criteria assumed important to the site selection process. The maximum cumulative suitability score for a land unit is 1000, which is re-scaled to a value ranging from 0 to 100.

The above equations were used both to assess the suitability of a land area for siting a production facility and for identifying those land areas that are suitable for manure application on the basis of modified criteria, weights and factor score. Figures 3a and 3b show the user interface, menu options, and dialog boxes designed to facilitate user interaction and navigation of the site selection component of LPRDSS. Modeling capabilities provided by ArcView GIS Spatial Analyst extension were used to calculate S_{ij}. Several scripts written in Avenue facilitated calculations of the values in the cumulative suitability grid. The output from the site selection can be visualized in map or table format.

Once the cumulative suitability score of a land area has been evaluated, it is checked against the minimum contiguous land area requirement stipulated for that production system (see Table 2). The minimum contiguous area criteria is established to ascertain that the land area identified is large enough to accommodate livestock housing needs as well as areas to construct lagoons, if needed. Overall, the site selection model provides the user with the capability of evaluating various livestock production strategies. These strategies are also summarized in Table 2.

Biophysical Model

The biophysical modeling component of LPRDSS is intended to evaluate the soil and water quality implications of different livestock production and nutrient management practices that could be applied to a watershed. In this component, the potential environmental impact of land application of manure is assessed through the use of the Soil and Water Assessment Tool (SWAT), a process-based computer simulation model developed to enhance the prediction of the impact of agricultural land management on water quality in ungaged watersheds and basins (Arnold et al, 1998). SWAT provides users with the capability to evaluate and compare the effectiveness of alternative land use and animal manure management scenarios as well as other agricultural management practices. An ArcView GIS – SWAT interface, developed by Di Luzio et al. (1997), has been incorporated into LPRDSS to enhance the use of watershed-level GIS database for modeling and to assist in the analysis and display of results. In this research, once the user has delineated suitable land areas for siting livestock facilities and for manure application, the biophysical modeling component then provides the tool for predicting impacts on soil and water quality and for analyzing 'what-if' scenarios of livestock production and environmental quality. For example, scenarios such as imposing various nutrient control options can be evaluated and compared with the baseline practice to quantify their water quality effectiveness.

SWAT is a hydrologic distributed parameter and continuous simulation model developed to predict the effect of alternative agricultural land use and land management practices on water quality. It predicts runoff, sediment yield, subsurface flow, and agricultural chemical leaching from relatively large ungaged watersheds and basins. The SWAT modeling database includes land management inputs such as fertilizer use, crop rotations, tillage operations, planting and harvesting dates, and pesticide application rates. The SWAT model also requires physical characteristics of the watershed and its subbasins such as climatic data (precipitation, temperature, humidity, etc.), soil properties (bulk density, content, etc.), topography (land slope and length), land cover, hydrogeology (channel length, slope, width, type, etc.), Mannings n values, USLE k factors, and groundwater. The input data

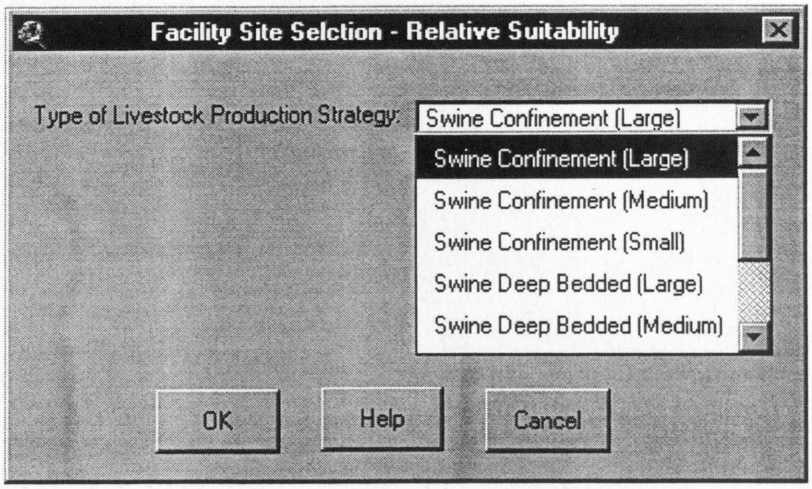

Figure 3. The dialog box in the Facility Site Selection DSS where the user can select a production strategy for the detailed analysis.

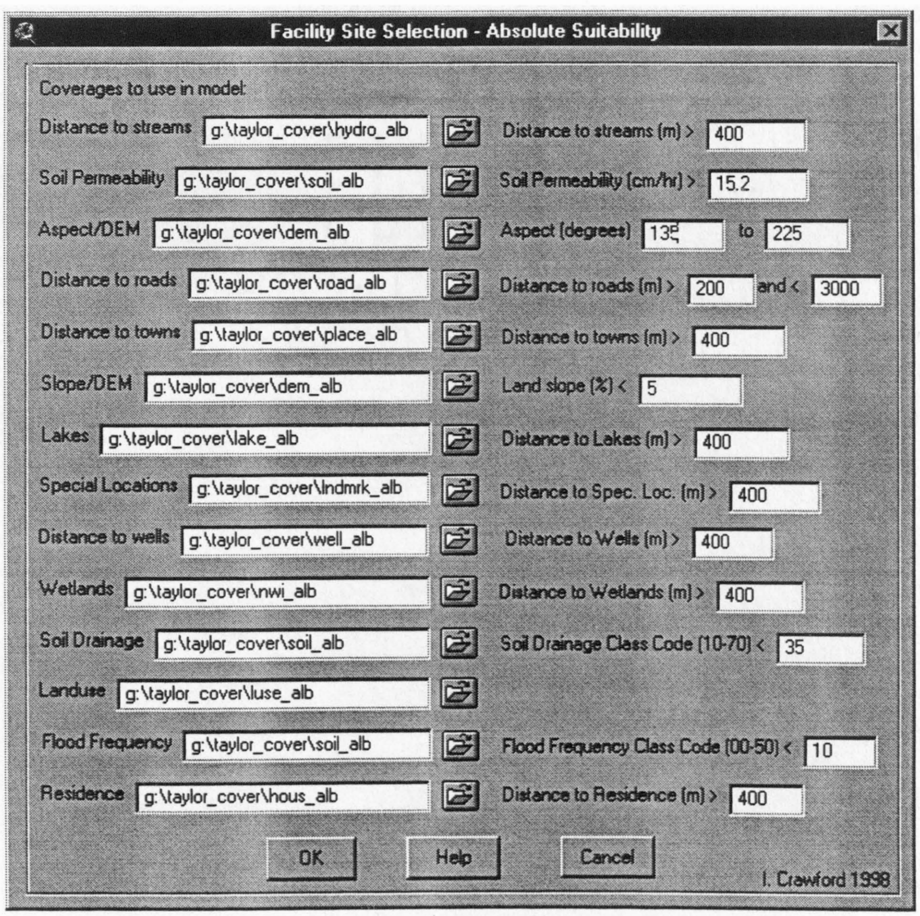

Figure 4. Layout of LPRDSS screen for identifying suitable production sites on the basis of absolute or exclusionary option.

Table 2. Livestock production strategy contiguous land area requirements.

Production Strategy	Small	Medium	Large
Swine Confinement	100 sows 0.8 ha	250 sows 1.2 ha	1,000 sows 4 ha
Swine Deep-bedded	100 sows 1 ha	250 sows 1.2 ha	500 sows 2 ha
Swine Pasture	50 sows 3.6 ha	100 sows 7.1 ha	250 sows 19 ha

required for the SWAT model, for each subwatershed within the basin of interest, is generated, organized and manipulated by the user interface designed as part of the ArcView GIS interface.

Previous applications of SWAT have shown promising results in simulating hydrologic functions. Srinivasan et al. have successfully used SWAT to simulate hydrologic and water quality functions in Texas including the Rio Grande/Rio Bravo Basins (1997), Seco Creek Watershed (1994), and the Naches River Basin (1993). Other researchers and scientists (Cho et al., 1995; Rosenthal et al., 1995; and Manguerra and Engel, 1998) have had similar success in other areas of the United States.

Odor Dispersion Modeling

Although the long-term solution to both the air and water quality problems from livestock production can be minimized by proper site selection, forecasting the spatial extent of odor dispersion is of practical importance. Atmospheric dispersion models provide an efficient tool to predict the transport of odor from livestock facilities, and for conducting environmental impact assessment of the livestock production enterprise. In this research, the odor dispersion modeling component of LPRDSS adopts a terrain-based Gaussian dispersion/diffusion model to compute the relative concentrations of atmospheric contaminants (or malodors) from a livestock facility or manure disposal site. The model accounts for different odor sources and local meteorological factors such as wind speed, direction, and frequency, and atmospheric stability. The odor transport model in LPRDSS is based on a simplified form of the Gaussian plume model developed in 1932 by O.G. Sutton and is given as:

$$\frac{C(x,y)}{Q} = \frac{1}{\pi\sigma_y\sigma_z v}\exp\left(-\frac{y^2}{2\sigma_y^2}\right) \tag{4}$$

In which C is the emission concentration (in micrograms per cubic meter) at any point x meters downwind of the source, and y meters laterally from the center of the plume; Q is the mass of the emission (in grams) per unit time; σ_y and σ_z are the downwind and crosswind coefficients of dispersivity, respectively; and v is the wind speed (in meters per second) on the ground surface. The assumptions incorporated into the equation include: (1) the odor source is located on the ground surface, (2) the wind speed remains uniform throughout the area and (3) the wind direction is constant. Another key assumption is that over short periods of time, steady-state conditions exist with regard to air pollution emissions and meteorological changes. The values of σ_y and σ_z vary with the turbulent structure of the atmosphere, height above the surface, surface roughness, sampling time over which the concentration is to be estimated, wind speed, and distance from the source (Lucas and Tseng, 1995). Pasquill (1961) characterized atmospheric stability into six classes based on meteorological factors such as solar radiation, cloud amount at night, and wind speed (Table 3). The dispersion parameters σ_y and σ_z are determined from the stability classes, depending upon the conditions listed in Table 31. For ground level agricultural sources the dispersion coefficients can be expressed as:

$$\sigma_y = k_1 + k_2 x^{k_3}$$

$$\sigma_z = k_4 + k_5 x^{k_6} \tag{5}$$

Where the coefficients k_1, k_2, k_3, k_4, k_5, k_6 are listed in Table 4 (Chen et al., 1998).

Table 3. Atmospheric Stability Categories[a]

	Day			Night	
	Incoming Solar Radiation				
Surface Wind Speed at 10 m (m/sec)	Strong	Moderate	Slight	Thinly overcast or >4/8 Low cloud	≤ 3/8 Cloud
< 2	A	A – B	B	E	F
2 - 3	A – B	B	C	E	F
3 - 5	B	B – C	C	D	E
5 - 6	C	C – D	D	D	D
> 6	C	D	D	D	D

[a] Class A is the most unstable and Class F is the most stable. The neutral class, D, should be assumed for overcast conditions during the day or the night, regardless of wind speed. Night refers to the period from 1 hour before sunset to 1 hour after sunrise (Lucas and Tseng, 1995).

Table 4. Coefficients in Equation 5.

Stability Class	k_1	k_2	k_3	k_4	k_5	k_6
A	-32.895	1.069	0.792	23.116	1.608×10^{-5}	2.494
B	-45.563	0.896	0.788	24.556	1.606×10^{-4}	1.923
C	15.792	0.259	0.871	-35.099	1.175	0.653
D	-12.616	0.328	0.811	-23.068	2.464	0.457
E	-14.619	0.356	0.771	-40.434	10.877	0.263
F	-11.067	0.208	0.791	-30.551	10.296	0.218

By integrating the odor dispersion model described above into LPRDSS, social or environmental concerns related to livestock odor and nuisance complaints can be quantitatively addressed. Furthermore, by integrating an atmospheric dispersion model with the user-friendly interface of ArcView GIS Spatial and 3-D Analysts extensions, a powerful tool is developed that allows users to interact and perform 'what if' site selection scenarios and to map and visualize potential areas for odor nuisance complaints.

In LPRDSS, a graphical interface manages the entire pollution modeling process. The graphical interface insulates the user from the complex algorithms associated with each model and provides an interactive environment for users to input relevant parameters such as wind speed and direction, location of the pollution source, and atmospheric conditions (Figure 4). The internal organization of the system was developed using Avenue. The Gaussian odor dispersion equation was integrated into LPRDSS by using the object-oriented programming language, Avenue, to facilitate data handling and manipulation, and the pre- and post-processing of the input data.

Example Application

Taylor County located in the southern Iowa (Figure 5) has an area of 135,168 ha, of which 132,880 ha of land were in farms in 1997 (Iowa Agricultural Statistics, 1998). Bedford, the county seat, is in the center of the county, about 192 km southwest of Des Moines, the state capital of Iowa. Taylor County is primarily rural and has only minor industry. About 41,712 ha (or 31%) of the total land area of Taylor County meets the U.S. Department of Agriculture soil requirements for prime farmland (NRCS, 1996). There are five dominant soil types in the county, including: Lamoni, Nira, Sharpsburg, Clearfield, and Adair (Figure 6). The soils of the nearly level upland divides are poorly drained. The loess soils of the gently sloping upland ridges are moderately well drained to somewhat poorly drained and the soil located in the flood plains are typically poorly drained. Subsurface drainage systems are present in almost all agricultural fields. Nearly all of this prime farmland is used for crops, mainly corn and soybeans (Figure 7). Crops grown on this land account for an estimated 50 to 60% of the county's total agricultural income each year. Like much of the U.S. Midwest, the farms in Taylor County have been increasing in size and decreasing in number. Between 1981 and 1997, the number of farms decreased from 980 to 746 but the average farm size increased from 138 to 156 ha (Soil Survey, 1986, Iowa Agricultural Statistics, 1998). Livestock production (swine, beef, poultry, and sheep) is the primary farming practice integrated with corn, soybeans, hay and small grains (e.g. wheat and oats). In 1997, approximately 71,500 hogs and pigs were produced in Taylor County. Grain is sold as a cash crop, but overall most is retained within the county for livestock production. Several towns have grain elevators for storage of grain.

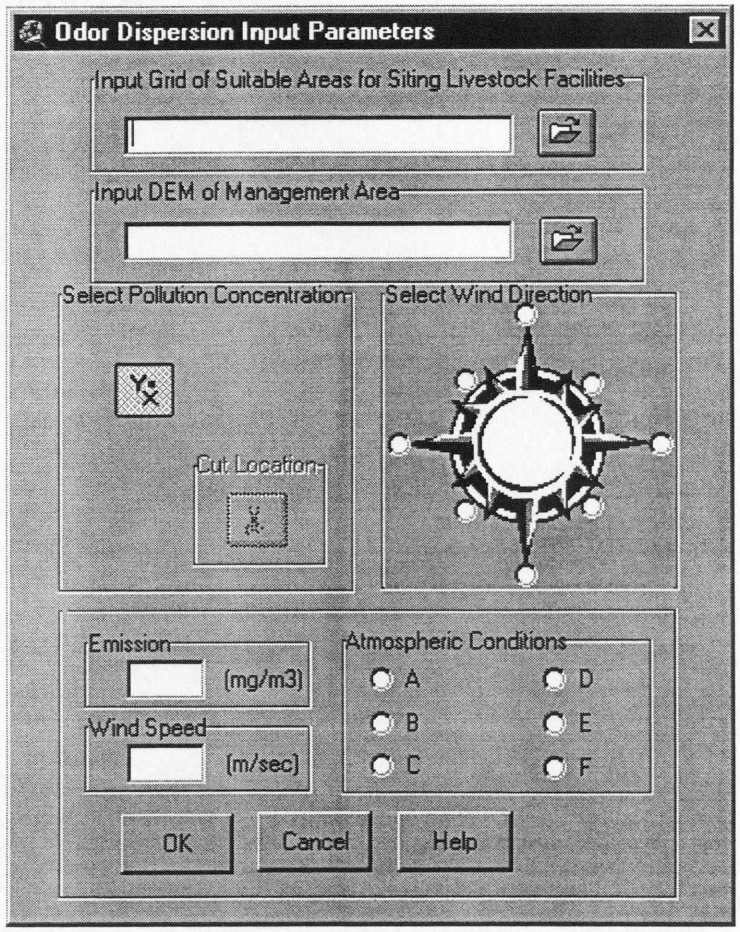

Figure 4. The dialog box in the odor dispersion model allows the user to input the data needed for modeling.

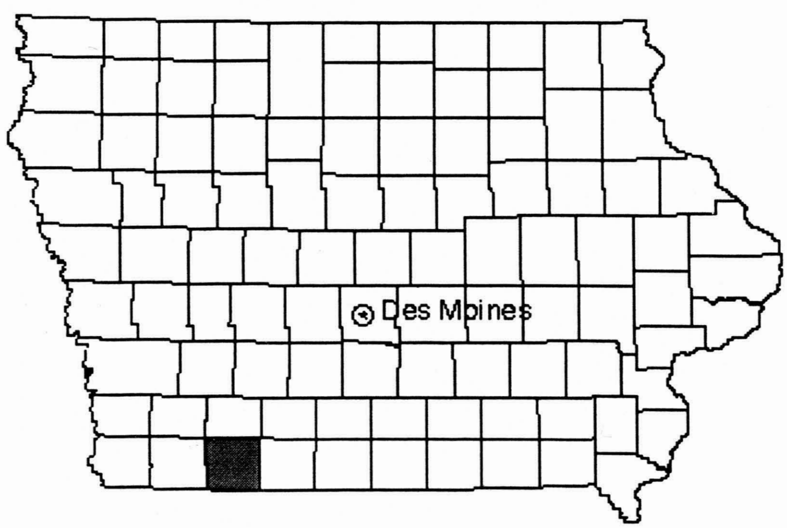

Figure 5. Location of Taylor County in Iowa

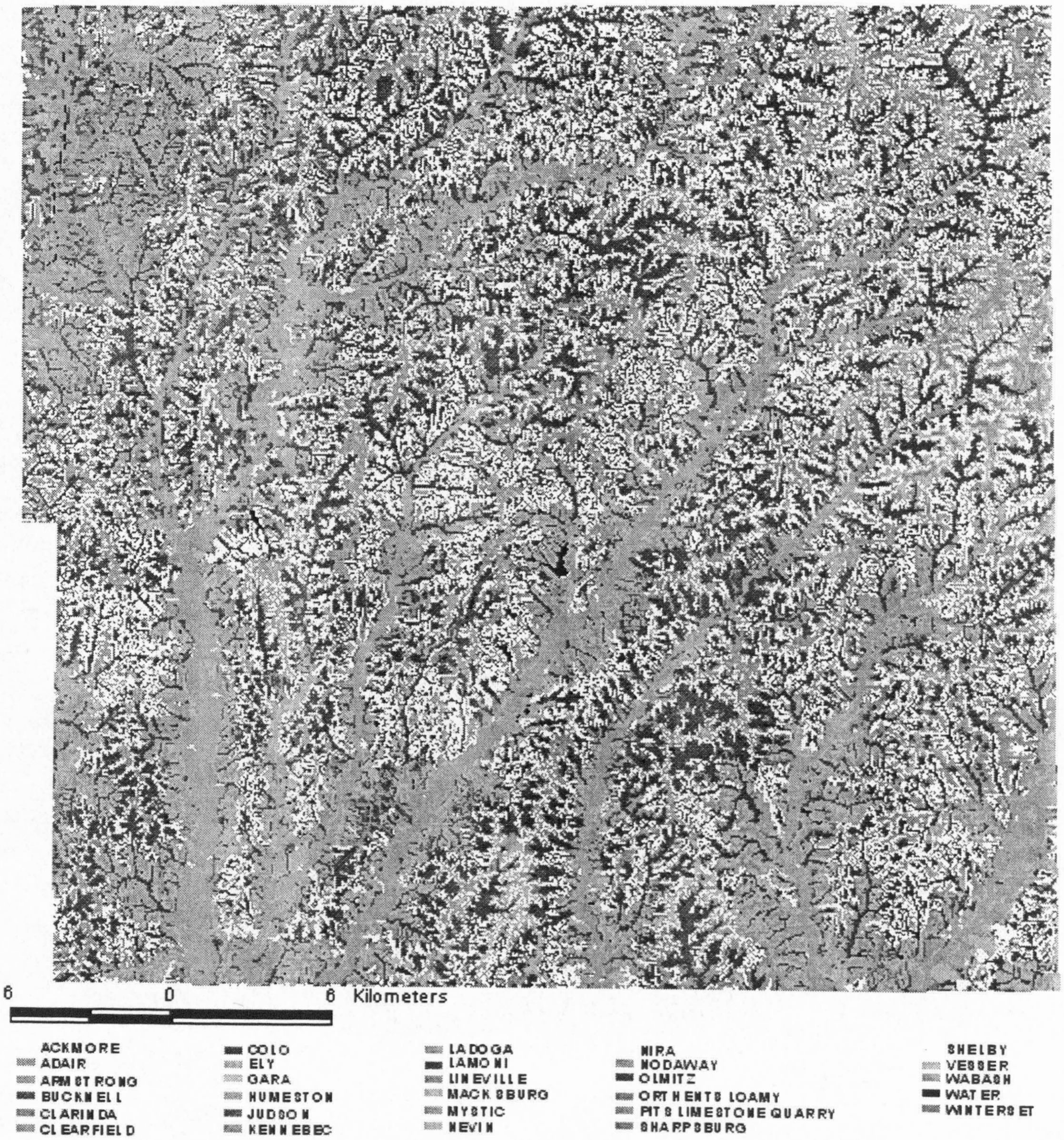

Figure 6. Soils in Taylor County, Iowa.

All of Taylor County is in the Missouri River basin. Streams flow generally in a south or southwesterly direction. The Nodaway River drains the northwestern part of the county, and the central part of the county is drained by the Hundred and Two Mile River and its tributaries and by Honey Creek. Reservoirs within Taylor County provide most of the drinking water for residents. Taylor County has about 340 ha of state-owned wildlife areas. Many forms of outdoor recreational activities are provided by the forested areas, rivers and creeks, and numerous small lakes and contribute to the economy of Taylor County.

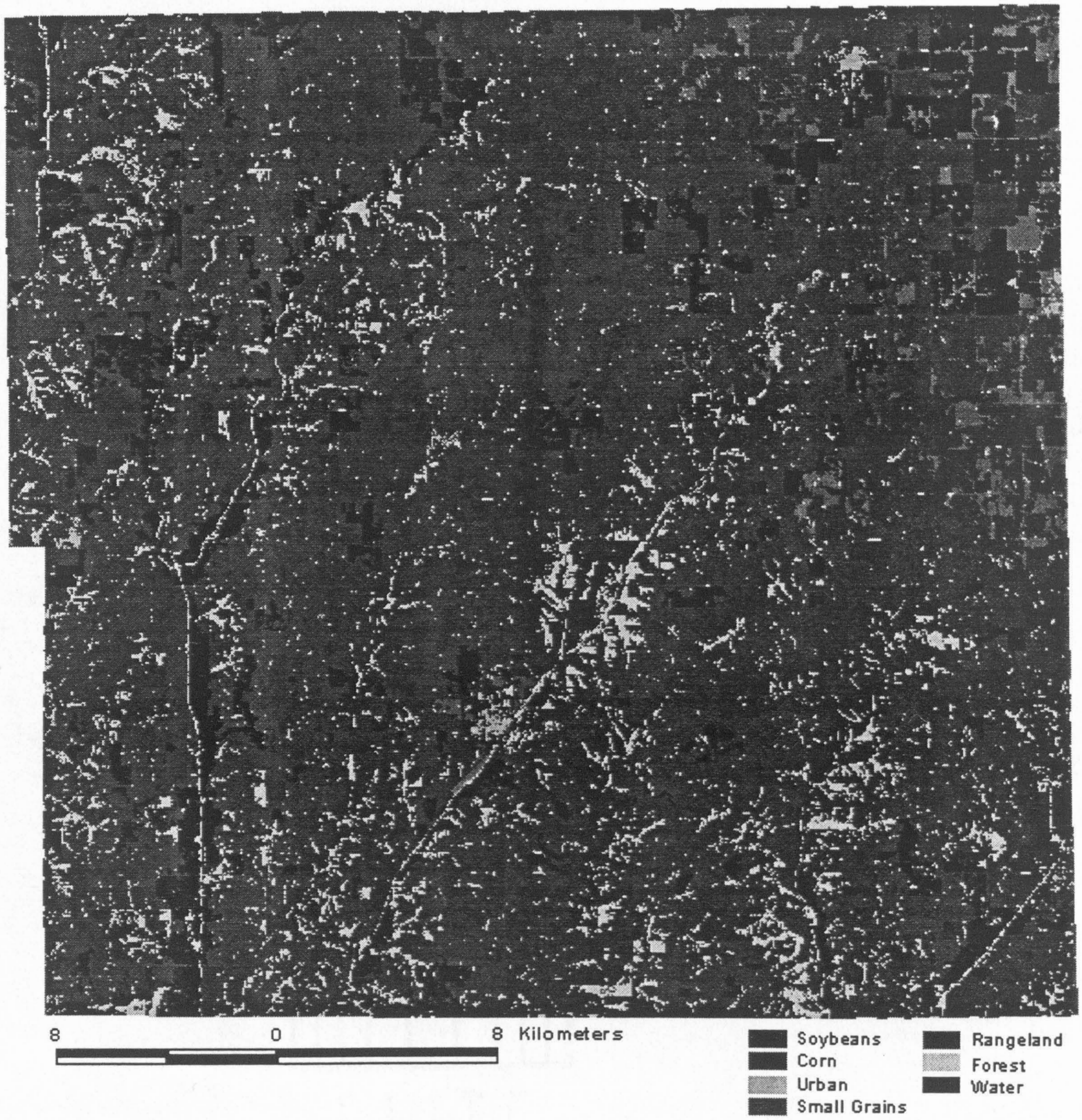

Figure 7. Land cover of Taylor County, Iowa.

The total annual precipitation for Taylor County is about 932 mm. Of this, 660 mm usually falls in April through September. In summer, the average temperature is 23°C, while during the winter, the average temperature is –3°C. The average relative humidity in mid-afternoon is about 60%. Humidity is higher at night, and the average at dawn is about 80%. The prevailing wind is from the northwest, and the average wind speed is about 21 km/hr during the spring months and sometimes gusting to about 64 km/hr.

In this example application, the LPRDSS was used to assess the environmental compatibility of siting large (1,000 sow) swine confinement facilities within Taylor County. Simulations were based on the assessment of the absolute site suitability criterion and assuming sites met the criteria outlined in Table 5. Suitable areas for the land application of manure were also determined using the absolute suitability site criterion and assuming the sites meet the criteria outlined in Table 6.

Using the absolute site-selection option and the criteria defined above, LPRDSS identified approximately 199 sites (or 1,257 ha) suitable in Taylor County for siting large confinement facilities (Figure 8), and about 5,223 ha of the total land area (or 3.86% of the land base) that are acceptable for manure application (Figure 9).

Table 5. Criteria used to select suitable areas for siting large swine confinement operations in Taylor County, Iowa (absolute option).

Criterion	Factor
Distance to streams, lakes, and wetlands	> 400 m
Distance to roads	> 200 m and < 3,000 m
Distance to incorporated areas and wells	> 400 m
Distance to residences and special locations	> 400 m
Soil permeability	> 15.2 cm/hr
Flood Frequency	Slight – None
Soil Drainage	Moderately well – Well drained
Aspect	135° - 225°
Slope	< 5%
Landcover	≠ Urban, Forest, Commercial, and Water

Table 6. Criteria used to identify potentially suitable manure application areas in Taylor County, Iowa (absolute option).

Criterion	Factor
Distance to streams, lakes, and wetlands	> 400 m
Distance to roads	> 100 m and < 3,000 m
Distance to incorporated areas and wells	> 400 m
Distance to residences and special locations	> 400 m
Soil permeability	> 15.2 cm/hr
Flood Frequency	Slight – None
Soil Drainage	Moderately well – Well drained
Aspect	90° - 250°
Slope	< 10%
Landcover	= Row Crops

Summary and Conclusions

In this paper a GIS-based decision support system (LPRDSS) for siting livestock production facilities and identifying suitable land areas for manure application was presented. The system provides an integrated, interactive, and user-friendly environment for planning sustainable livestock production systems that are not only environmentally sensitive but also meet regulatory constraints.

The DSS integrates environmental databases, ArcView GIS, biophysical models, and an atmospheric (Gaussian) dispersion model into an environment that allows rapid assessment of the air, soil, and water quality issues associated with confinement animal production systems. The goal of the DSS is to improve the analytical ability of resource agencies, producers, and decision-makers to select environmentally-sound and socially acceptable livestock production sites. The DSS incorporates two models – an atmospheric dispersion model and a biophysical model – that enables users to interactively address issues of odor and water quality of the livestock production system. It is important to note that LPRDSS is an analytical tool and should be used as an aid in the decision-making process by identifying optimal land areas for in-depth assessment.

As currently structured, LPRDSS operates on a desktop computer running Windows™. An example application to identify suitable land areas of Taylor County, Iowa, for siting large hog confinement operations and for manure application has demonstrated the effectiveness and efficiency of LPRDSS as an analytical tool and decision making environment.

References

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development. Journal of the American Water Resources Association 34:73-89.

Burrough, P.A. 1986. Geographical Information Systems for Land Resource Assessment. Oxford: Clarendon Press.

Chen, Y.C. S.J. Hoff, and D.S. Bundy. 1998. Modeling and Evaluation of Dispersal Parameters for Odors from Agricultural Sources. Journal of Environmental Systems 26:27-39.

Cho, S.M. G.D. Jennings, C. Stallings, and H.A. Devine. 1995. GIS-Based Water Quality Model Calibration in the Delaware River Basin. Paper No. 952404. St. Joseph, MI: American Society of Agricultural Engineers.

Di Luzio, M., R. Srinivasan, and J. G. Arnold. 1997. An Integrated User Interface for SWAT using ArcView and Avenue. Paper No. 972235. St. Joseph, MI: American Society of Agricultural Engineers.

Freese, B. 1995. Pork Powerhouses. Successful Farming. 92:20-24.

Freese, B. 1997. Pork Powerhouses. Successful Farming. 95:22-26.

Gar-On Yeh, A. and X. Li. 1998. Sustainable Land Development Model for Rapid Growth Areas Using GIS. International Journal of Geographic Information Science 2:169-189.

Goodrich, J.A. B.W. Lykins Jr., and R.M. Clark. 1991. Drinking Water from Agriculturally Contaminated Ground Water. Journal of Environmental Quality 20:707-717.

Hendrix, W.G. and D.J.A. Buckley. 1992. Use of a Geographic Information System for Selection of Sites for Land Application of Sewage Waste. Journal of Soil and Water Conservation 47:271-275.

Hynes, H. B. N. 1971. The Biology of Polluted Waters. Toronto, Canada: University of Toronto Press.

Iowa Agricultural Statistics. 1998. 1998 Iowa Agricultural Statistics. J.K. Sands and Holden (Editors). Des Moines, IA: Iowa Department of Agriculture and Land Stewardship.

Jain, D.K., U.S. Tim and R. Jolly. 1995. Spatial Decision Support System for Planning Sustainable Livestock Production. Computers, Environment, and Urban Systems 19:57-75.

Joao, E. M. and S.J. Walsh. 1992. GIS Implications for Hydrologic Modeling: Simulation of Nonpoint Pollution Generated as a Consequence of Watershed Development Scenarios. Computers, Environment and Urban Systems 16:43-63.

Kohl, K. and J. Lorimor. 1997. Swine Manure Management and Iowa's Manure Law. Engineering 1-1. Iowa State University Extension, Ames, Iowa.

Lucas, R.D. and A.S. Tseng. 1995. Handbook of Air Pollution Control Engineering and Technology. pp 317-336. J.C. Mycock, J.D. McKenna, L. Theodore (Editors). CRC Press, Inc.

Manguerra, H.B. and B.A. Engel. 1998. Hydrologic Parameterization of a Watershed for Runoff Prediction using SWAT. Journal of American Water Resources Association 34:1149-1162.

Pasquill, F. 1961. The Estimation of the Dispersion of Windborne Material. Meteorological Magazine.

Rosenthal, W.D., R. Srinivasan, J.G. Arnold. 1995. Alternative River Management Using a Linked GIS-Hydrology Model. Transactions of the ASAE 38:738-790.

Srinivasan, R. T.S. Ramanarayanan, R. Jayakrishnan, H. Wang. 1997. Hydrologic Modeling of Rio Grande/Rio Bravo Basin. Paper No. 972236. St. Joseph, MI: American Society of Agricultural Engineers.

Srinivasan, R. and B.A. Engel. 1994. A Spatial Decision Support System for Assessing Agricultural Nonpoint Source Pollutiion. Water Resources Bulletin 30:441-452.

U.S. Environmental Protection Agency. 1997. National Water Quality Inventory: 1996 Report to Congress (EPA 841-R-97-008). Office of Water. Washington, D.C.: U.S. Environmental Protection Agency.

Wolfe, M.L. and P.N. Deliman. 1990. Optimizing Dairy Site Selection Using a Geographic Information System. In Proceedings: Application of Geographical Information Systems, Simulation Model, Knowledge-based Systems for Landuse Management. November 12-14, 1990. Blacksburg, VA: Department of Agricultural Engineering, Virginia Polytechnic Institute and State University.

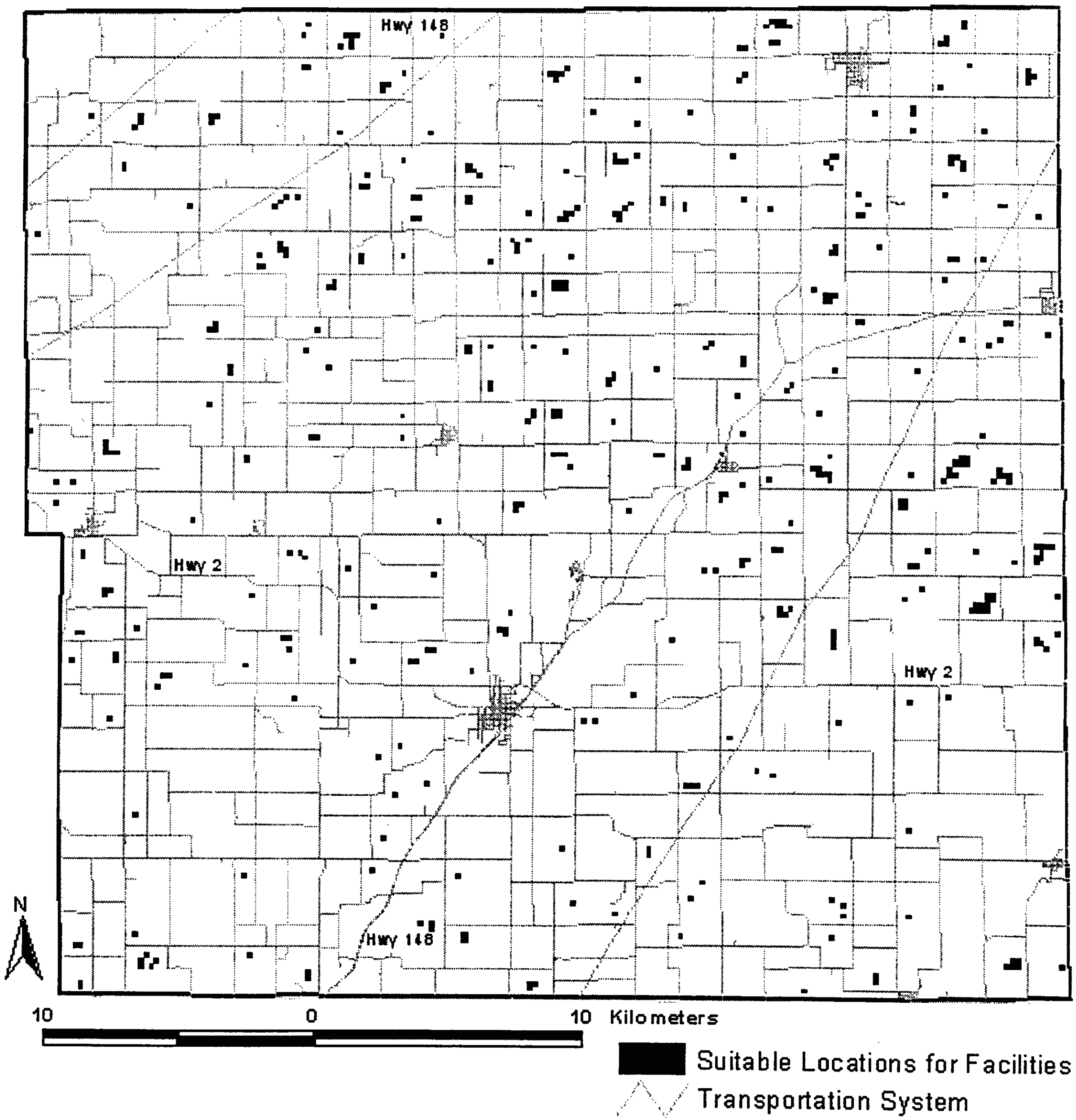

Figure 8. Location of suitable sites for locating large swine confinement operations in Taylor County, Iowa

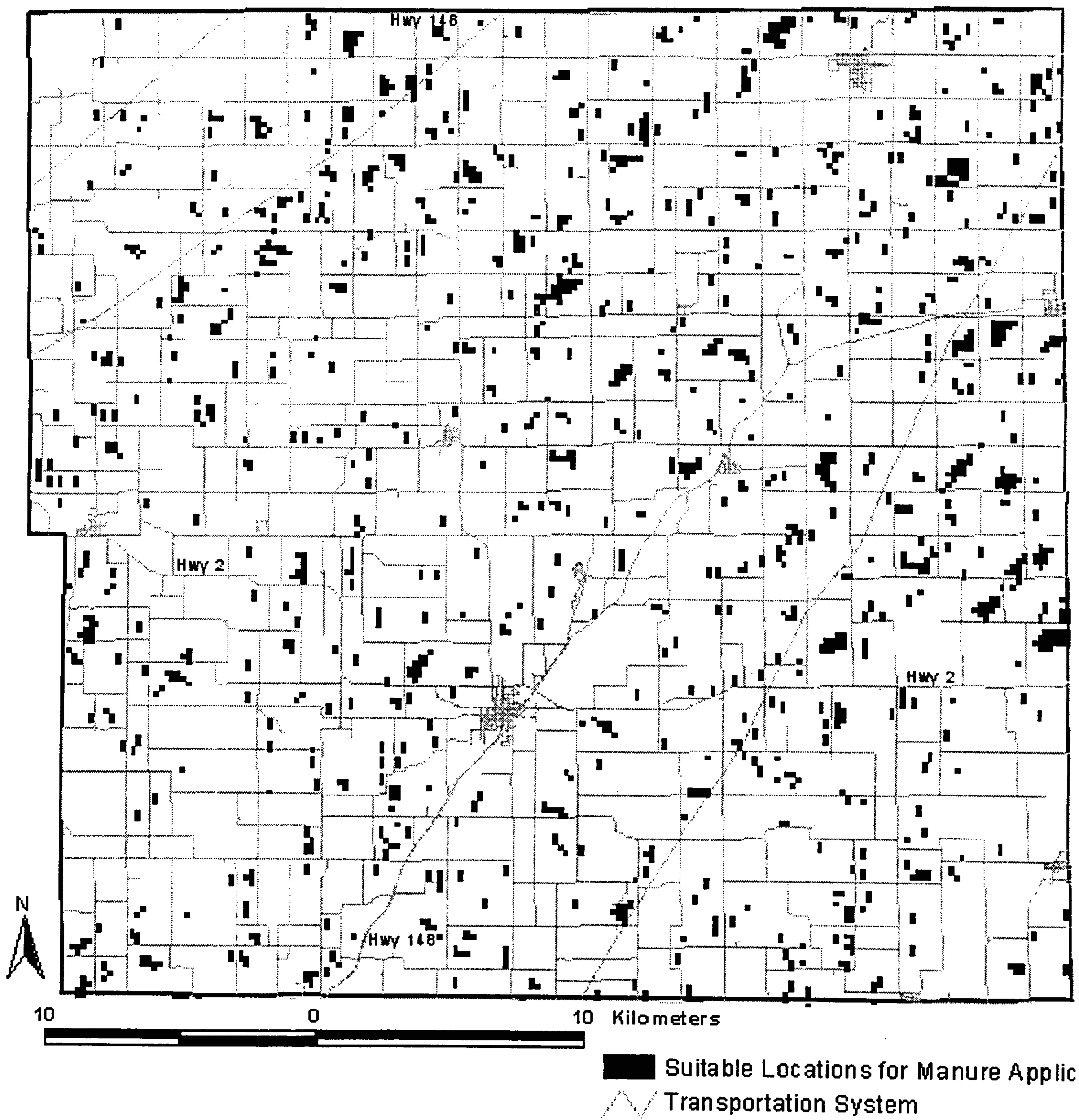

Figure 9. Location of suitable sites for land application of animal waste in Taylor County, Iowa.

CHAPTER 3. SIMULATING ODOR TRANSPORT FROM LIVESTOCK FACILITIES USING ARCVIEW GIS

A paper to be submitted to Journal of Environmental Quality

I. M. Crawford and U. S. Tim

Abstract

This paper presents the development and implementation of a simplified, spatially explicit model that simulates odor transport from livestock facilities and manure application areas. Odorous gaseous, such as methane, ammonia, and other gaseous are a health hazard and nuisance to neighbors close to livestock facilities. The model is based on a simplified form of the Gaussian plume model and was integrated with ArcView GIS. The resulting analytical tool was incorporated in a livestock production decision support system (LPRDSS). This component of the LPRDSS allows users to interact with the data and perform 'what if' scenarios to identify and visualize potential air-quality problems. The model accounts for different odor sources, the influence of topography, and wind speed and wind direction. An example application of the model to Taylor County, Iowa, demonstrates the unique capabilities of the model.

Introduction

Air pollution can be defined as the presence of air contaminants under conditions that are injurious to humans, plants, animals or property, or which unreasonably interferes with the enjoyment of life and property (Loehr, 1974). In recent years, air pollution concerns, in the form of odor from livestock operations, has received increased attention. Consequently, numerous research studies have been conducted to reduce odor emissions from livestock operations. These studies range from modifying animal feed and nutrition to reduce nitrogen excretion (Erickson et al., 1998); implementing windbreak walls and shelterbelts around facilities and waste lagoons to limit dust and odor emissions (Bottcher, 1998); evaluating composting methods to produce less odor (Weichenthal et al., 1998); and incorporating additives into animal manure to reduce the production of volatile organic components from decomposing manure stored within buildings (Bundy and Hoff, 1998). While these methods are effective in reducing the odor emitted from a livestock operation, odor nuisance complaints from neighboring populations still persist. Specifically, nuisance complaints from neighbors of large concentrated animal feeding operations have increased with the increase of people moving from cities to rural areas. Neighbors complain that livestock odors adversely affect the quality of their lives, cause unknown long-term health problems, and reduce real estate property values. For these reasons, determining suitable locations for siting livestock facilities and the effect of the siting decisions on neighboring communities present a formidable challenge to the research community.

Several sources of odor emissions from livestock operations have been identified, including the facility, manure storage and treatment facilities, and land application sites. Emissions from these sources contribute to local odor associated with swine production and to regional and global air quality issues. It is estimated that domestic animal production accounts for approximately 40 to 45% of the total annual global emissions of ammonia (Hasimoglu, 1998). Weather patterns, air temperature, air moisture levels, solar insulation, particulate concentration, and human tolerances all interact to define the extent that a neighbor will detect and be offended by livestock odors. (Loehr, 1974).

Although the long-term solution to odor and other environmental pollution problems is clearly to reduce the emissions of the pollutant, forecasting the spatial distribution of odor contaminants and their impacts on neighbors is a task of great practical importance. Odor dispersion models provide a tool for predicting pollutant dispersal and for conducting air quality impact assessment that can drive regulatory programs (Ortolando, 1997). Despite their mathematical simplicity, these models allow us to improve our understanding of the physical and chemical processes involved in the transport of air pollutants (Utrecht, 1997), and provide an effective tool for management decision-making (Grayson, et al, 1992). When combined with emerging geospatial information technologies, such as geographic information systems (GIS), odor dispersion models provide rapid and timely assessment of the spatial extent and magnitude of the livestock air quality problem.

This paper describes the development and application of a spatially explicit odor dispersion model. The primary objectives of the study were to: (1) develop an effective easy-to use odor pollution model that addresses the potential environmental and social implications of livestock production in terms of its contribution to odor nuisance complaints from neighbors, (2) provide a convenient method to input data for the model, (3) provide an enhanced visualization interface for the interpretation of results, and (4) provide an efficient tool that operates on a standard desktop computer, where most future modeling and GIS applications will reside.

Methods and Materials

The livestock odor and dispersion model, described in this paper, was developed as a component of the livestock production decision support system (LPRDSS). LPRDSS consists of a multi-criteria site evaluation module, a biophysical module, and an odor dispersion module. The DSS was designed primarily to assist planners and decision-makers in planning livestock production systems, specifically to select optimal land areas for siting livestock production facilities and to analyze the environmental impacts of the production system. The LPRDSS site evaluation model consists of a multi-criteria spatial decision model that incorporates fourteen different environmental, social, and political regulatory variables that influence the decision making process (Table 1). By performing spatial analysis and modeling using the multi-criteria and environmental databases, suitable areas for siting livestock facilities and manure application can be delineated for further analysis of the soil, water, and air quality impacts through the use of biophysical and odor dispersion models.

Table 1. Environmental, social, political and regulatory variables used in the LPRDSS.

Distance to streams, lakes, wetlands, and wells
Distance to roads
Soil permeability
Aspect
Distance to incorporated areas and special locations (schools, churches, etc.)
Land slope
Soil Drainage
Current land-use
Flood frequency
Distance to residences

The odor model in LPRDSS introduces both a social and environmental issue into the livestock site selection process, by allowing decision-makers to determine the impacts of livestock odor on neighboring communities and residences. The model uses a terrain-based Gaussian dispersion/diffusion equation to compute the relative concentrations of odors from a livestock facility or manure application area. It assumes a time-averaged distribution of the plume and incorporates changing meteorological conditions such as atmospheric stability, wind speed, direction, and frequency. The model is used to determine the environmental impacts of a concentrated release from an existing or proposed facility. A simplified form of the terrain-based dispersion/diffusion equation can be written as:

$$\frac{C(x,y)}{Q} = \frac{1}{\pi \sigma_y \sigma_z v} \exp\left(\frac{y^2}{2\sigma_y^2} \right) \tag{1}$$

In which C is the emission concentration (in micrograms per cubic meter) at any point x meters downwind of the source, and y meters laterally from the center of the plume; Q is the mass of the emission (in grams) per unit time; σ_y and σ_z are the downwind and crosswind coefficients of dispersivity, respectively; and v is the wind speed (in meters per second) on the ground surface. The σ_y and σ_z are not defined explicitly by the mathematical assumptions and, therefore must be determined empirically. The values of σ_y and σ_z vary with the turbulent structure of the atmosphere, height of the pollutant source above the ground surface, surface roughness, sampling time over which the concentration is to be estimated, wind speed, and distance from the source (Lucas and Tseng, 1995). Pasquill (1961) characterized the atmospheric stability into six major classes based on meteorological factors such as solar radiation, cloud density at night time, and wind speed (Table 2). The dispersion parameters σ_y and σ_z are determined from the stability classes, depending upon the condition listed in Table 2. For sources originating at the ground level dispersion coefficients can be expressed as:

$$\sigma_y = k_1 + k_2 x^{k_3}$$

$$\sigma_z = k_4 + k_5 x^{k_6} \quad (2)$$

where the coefficients k_1, k_2, k_3, k_4, k_5, k_6 are listed in Table 3 (Chen et al., 1998).

Table 2. Atmospheric Stability Categories[a]

Surface Wind Speed at 10 m (m/sec)	Day: Incoming Solar Radiation			Night	
	Strong	Moderate	Slight	Thinly overcast or >4/8 Low cloud	≤ 3/8 Cloud
< 2	A	A – B	B	E	F
2 - 3	A – B	B	C	E	F
3 - 5	B	B – C	C	D	E
5 - 6	C	C – D	D	D	D
> 6	C	D	D	D	D

[a] Class A is the most unstable and Class F is the most stable. The neutral class, D, should be assumed for overcast conditions during the day or the night, regardless of wind speed. Night refers to the period from 1 hour before sunset to 1 hour after sunrise (Lucas and Tseng, 1995).

Table 3. Coefficients in Equation 5.

Stability Class	k_1	k_2	k_3	k_4	k_5	k_6
A	-32.895	1.069	0.792	23.116	1.608×10^{-5}	2.494
B	-45.563	0.896	0.788	24.556	1.606×10^{-4}	1.923
C	15.792	0.259	0.871	-35.099	1.175	0.653
D	-12.616	0.328	0.811	-23.068	2.464	0.457
E	-14.619	0.356	0.771	-40.434	10.877	0.263
F	-11.067	0.208	0.791	-30.551	10.296	0.218

Although the Gaussian air dispersion/diffusion models are powerful tools for predicting the transport, spatial distribution, and concentrations of air pollutants, it is widely recognized that such models tend to have deficiencies in their data handling and visualization capabilities. In order for an air pollutant dispersion model to be effective, data input and time requirements must be efficient for the user. Also, the potential effects of a release must be communicated in an understandable manner so that the results can be properly evaluated by the decision-makers. For these reasons, a GIS represents an effective tool not only for enhancing the use of these models, but also for providing the tools for data visualization. GIS enables resource managers to collect, store, organize, analyze, and display large amounts of environmental, social, and infrastructure data needed for atmospheric pollution modeling and visualization. GIS provides the tools that enhance the coupling of both simple and complex chemical transport models.

There are numerous methods for integrating models with GIS as discussed by Steyaert (1996) and Tim (1996). These strategies include loose coupling, close coupling, and full integration where the model source code is fully embedded inside the GIS. In the full integration strategy, a programming language such as Avenue, ArcView GIS's object oriented programming language, can be used to establish linkages between the various program modules making them share a common database for seamless modeling. Other advantages of the full integration strategy include a common data structure or data model to represent real world features and integrated visualization of model results using GIS functions. Compared to full integration, loose coupling of models and GIS involves establishing a procedure to transfer data between the GIS and the models, while the close coupling strategy involves an enhanced form of loose coupling (Tim, 1996). Because of its attractiveness and simplicity, the full integration strategy between the odor model and ArcView GIS was established for this project.

Other benefits of integrating models with GIS includes the advanced visualization techniques provided by GIS, and the recent advancement of desktop GIS and interactive graphical interfaces to make GIS more user-friendly. A trend within the GIS industry is the recent advances in point-and-click interfaces and visualization that stimulate acquisition of insights into and solutions of the problem addressed. Innovations in graphical user interfaces have brought powerful GIS functionality to a broader group of users. Also, with the reduction in cost and increased performance of desktop computers there has been increased interest in the use of GIS in many environmental and natural resource applications.

The ArcView GIS was used to manipulate and manage the input data required by the odor dispersion/diffusion model and to assist with the display and visualization of the output data. ArcView GIS, developed by Environmental Systems Research Institute, Redlands, California, is a powerful and flexible desktop mapping program that provides GIS capabilities in a user-friendly context. Major features of ArcView include: easy to use interface, extensive data analysis and modeling functions, comprehensive application development environment, high-end geocoding and address matching capabilities, and modules for seamless client-server access to distributed data and data warehouses (ESRI, 1998). By integrating the odor dispersion model with the user-friendly interface of ArcView GIS (including the Spatial Analyst and 3-D Analyst Extensions), a powerful tool was developed that allows users to easily interact with the data and model, perform 'what if' scenarios, visualize, and display potential locations of air-quality concerns from a livestock facility.

In this study, Equations 1 and 2 were fully integrated into ArcView GIS by using Avenue, the ArcView's premiere, object-oriented programming and scripting language. System integration and customization was necessary to facilitate data handling, data manipulation, and pre- and post-processing of the data required by the model. A customized dialog box (Figure 1), developed by using ArcView's Dialog Designer module, enables users to define the odor source concentration, wind direction and speed, and atmospheric stability conditions. A graphical user interface established between ArcView and the modeling equations allows users to efficiently manipulate large quantities of spatial data and to navigate the entire modeling environment (e.g. databases, models, etc.). Once the relevant data has been entered into the user interface, the model simulates the movement of pollutants and displays the results in the form of contours or isolines of relative pollutant concentrations. These results can than be visualized in three-dimensions, through the ArcView's 3-D Analyst Extension, by draping the simulated dispersion plumes onto a digital elevation model of the area under investigation. An example application in the next section will demonstrate the capability of the odor dispersion/diffusion modeling component of LPRDSS.

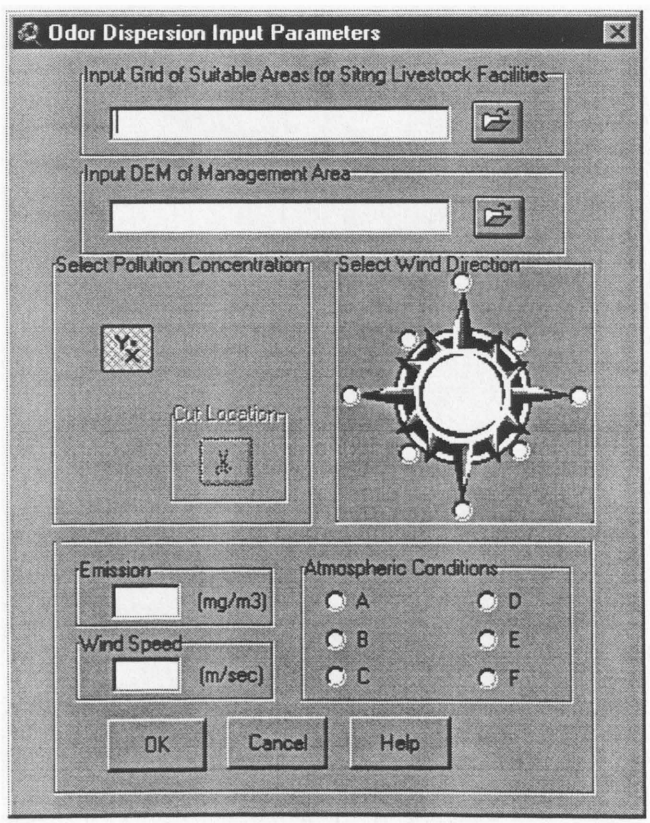

Figure 1. The dialog box in the odor dispersion model allows the user to input the data needed for modeling.

Example Applications and Results

Taylor County, located in southern Iowa, (Figure 2) was selected to demonstrate the applicability of the livestock odor dispersion model. Taylor County has an area of 135,168 ha of which 132,880 ha of land were in farms in 1997 (Iowa Agricultural Statistics, 1998). Bedford, the county seat, is located about 192 km southwest of Des Moines. Taylor County is primarily rural and has very few industries. About 41,712 ha (or 31%) of the total land area of Taylor County meets the U.S. Department of Agriculture soil requirements for prime farmland (NRCS, 1996). Nearly all of this prime farmland is used for crops, primarily corn and soybeans. Crops grown on this land account for an estimated 50 to 60% of the county's total annual agricultural income. Like much of the U.S. Midwest, farms in Taylor County have been increasing in size and decreasing in number. Between 1981 and 1997, the number of farms decreased from 980 to 746 but the average farm size increased from 138 to 156 ha. (Soil Survey, 1986; Iowa Agricultural Statistics, 1998). Livestock production (swine, beef, poultry, and sheep) is the primary farming practice integrated with corn, soybeans, hay, and small grains (e.g. wheat and oats). Approximately 71,500 hogs and pigs were produced in the county in 1997.

The total annual precipitation for Taylor County is about 932 mm. Of this, 660 mm falls between April and September. During summer, the average temperature is 23° C, while winter averages about –3° C. The average relative humidity in mid-afternoon is about 60%. Humidity is higher at night, and the average at dawn is about 80%. The prevailing wind is from the northwest, with an average wind speed of about 21 km/hr during the spring months and sometimes gusting to about 64 km/hr.

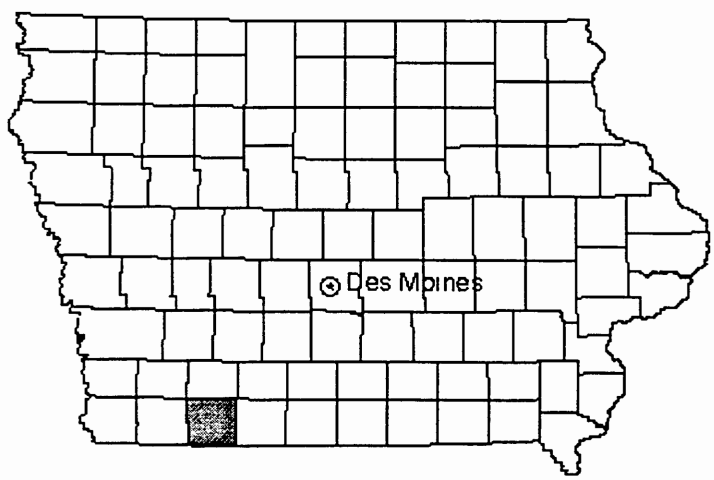

Figure 2. Location of Taylor County in Iowa.

To facilitate assessment of livestock air quality issues in Taylor County, the site selection module of LPRDSS was used to delineate land areas for siting large confinement operations. The site selection module consists of a spatial weighting scheme of 14 different environmental, social, political, and regulatory variables affecting livestock facility siting and the land areas to apply the manure. Representing these variables are a set of site selection criteria, including. distance from streams, roads, lakes, wetlands, and wells (agricultural drainage and drinking); proximity to residences, sinkholes, incorporated and other public areas, and landmarks such as churches and schools; topographic features and physical characteristics, such as land slope and aspect; and environmental factors such as soil drainage, soil permeability, flood potential, and land cover. Each variable is subdivided into categories based on regulatory and/or scientific criteria, and each criterion is subsequently assigned a weight based on its suitability. In the research, the environmental, social, and political/regulatory conditions, as outlined in Table 3, had to be met for a land area to be identified as suitable for siting an operation. The site must also meet a four hectare contiguous land area requirement for 1,000 sow units. Figure 3 shows the spatial distribution of the land areas suitable for siting large swine confinement operations in Taylor County, Iowa. About 1,257 ha was determined suitable for siting 199 facilities. The LPRDSS was effective in reducing the number of candidate sites in Taylor County, subsequently enhancing selection of optimal sites. These sites were subjected to air quality or odor pollution analysis using the modeling framework described in this paper.

Table 3. Criterion used to select suitable areas for siting large swine confinement operations.

Criterion	Factor
Distance to streams, lakes, and wetlands	> 400 meters
Distance to roads	> 200 meters and < 3,000 meters
Distance to incorporated areas and wells	> 400 meters
Distance to residences and special locations	> 400 meters
Soil permeability	> 15.2 centimeters/hour
Flood Frequency	Slight - None
Soil Drainage	Moderately well – Well drained
Aspect	135° - 225°
Slope	< 5%
Land-use	≠ Urban, Forest, Commercial, and Water

Performance and applicability of the odor dispersion/diffusion modeling framework was tested using three scenarios of climate conditions typical for Iowa. These scenarios are summarized in Table 4, and the parameters for each scenario were input into the modeling environment through dialog menus and boxes described previously. The model requires a polygon coverage to identify the management boundary and a DEM for 3-D visualization is optional. In this study, the county boundary was used for the management area boundary, from which a raster coverage with a cell size of 200 m was created.

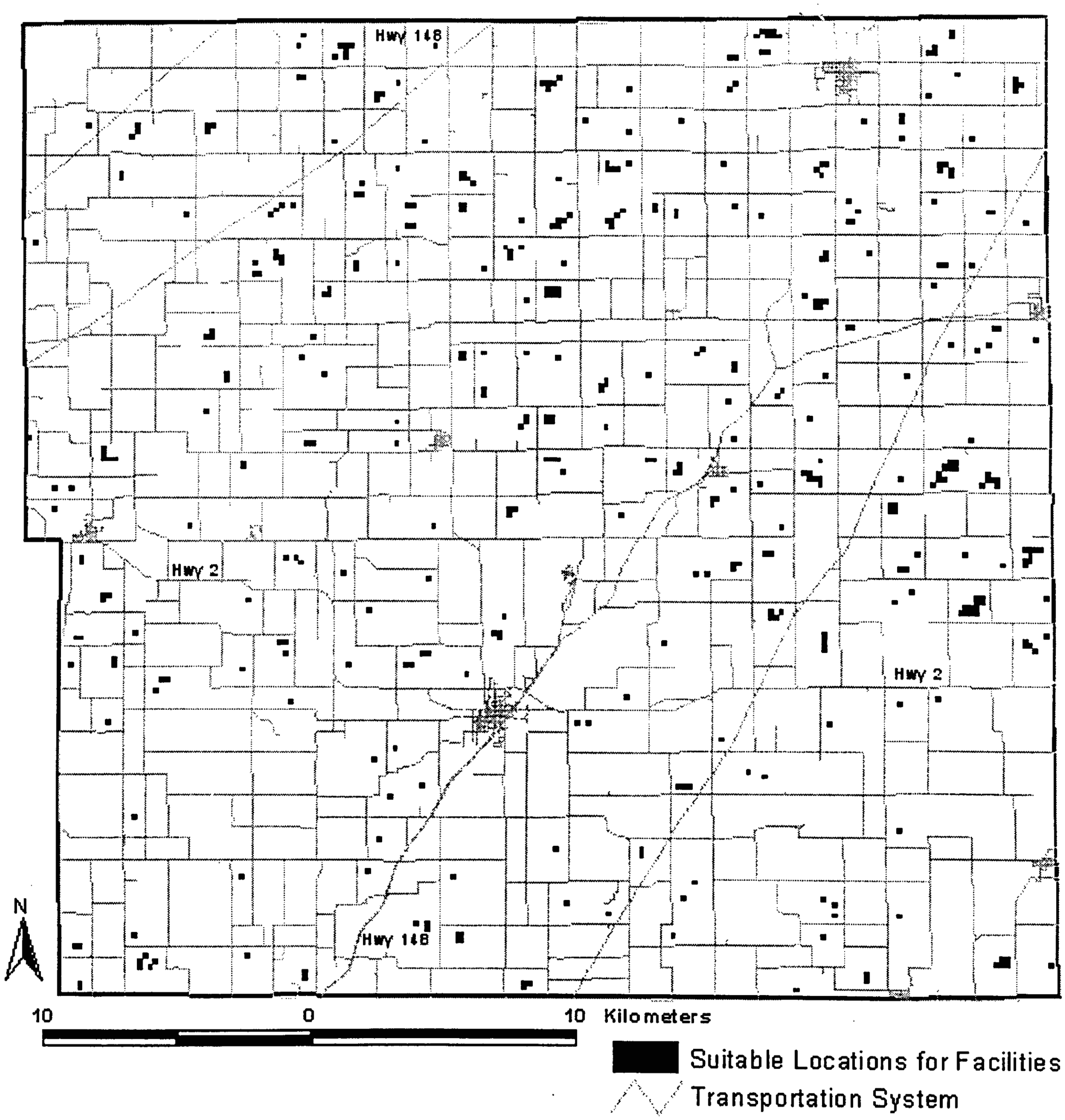

Figure 3. An example output map of suitable locations for siting large swine confinement facilities in Taylor County, Iowa.

Table 4. Odor dispersion case study scenario parameters.

Parameters	Scenario 1	Scenario 2	Scenario 3
Wind Speed, υ	6 m/s	4 m/s	1 m/s
Wind Direction	West	West	West
Atmospheric Cond.	C	B	A

Figures 4a, 4b, and 4c show the non-spatial display of results of scenario 1, scenario 2, and scenario 3, respectively. These scenarios were used to test the stability of the odor dispersion/diffusion model before application at the regional-level. Scenario 1 with a moderate wind speed of 6 m/s affected a larger land area downwind than scenarios 2 and 3. Figures 4b and 4c show the results for lower wind speeds of 4 m/s and 1 m/s with different atmospheric conditions. Figure 5 shows the results of a predicted spatial distribution of odor plumes for an area in northern Taylor County with a wind velocity of 4 m/s from the west. All but one potential livestock facility will have an adverse affect on a residence under this scenario. The decision-maker can than remove the potential pollution sites from consideration of siting a large swine confinement operation and/or continue to perform 'what-if' scenarios using other atmospheric conditions. Each relative concentration isoline indicated the maximum extent of the plume used to assess impact on neighbors. The results are displayed in 2-D and 3-D to enhance display visualization, and interpretation. In the 3-D display, a DEM was used to create a digital terrain of the management boundary, and the odor plume is converted to an ArcView 3-D shape file. The 3-D environment, provided by ArcView's 3-D Analyst Extension, which allows the user to rotate, zoom in and zoom out, and navigate through the area affected by odor pollution. The base coverage for the 3-D display is a digital terrain model of the county, and the results were draped on top of the base coverage.

Conclusions

The modeling of odor pollution from animal facilities not only allows users to predict future air quality impacts, but also to propose rational and cost-effective remedial strategies. The model allows a user to test hypothesis and learn about how key meteorological parameters affect the spatial distribution of odor. Overall, the odor dispersion model integrated with ArcView GIS is a practical solution to remedy data handling and visualization deficiencies with existing atmospheric models.

Similar results for different source locations and wind directions can be conducted with a similar approach. The output from the model can be viewed in a 2-D or 3-D environment and other information such as transportation systems, residences, etc. draped with the output odor plume to provide new insights and, ultimately to more informed and technically-defensible decision making. The 3-D environment provided by ArcView's 3-D Analyst provides an exceptional visualization tool for viewing the study area.

Further research can be conducted to improve Equation 1 of the model. For example, the model could also be improved by accounting for time and allowing the output to be displayed as a dynamic output rather than static. A final suggestion would be to develop a web-based interface using, for example, ArcView's Internet Map Server to deliver the capabilities of the modeling environment to a wide range of users and audiences.

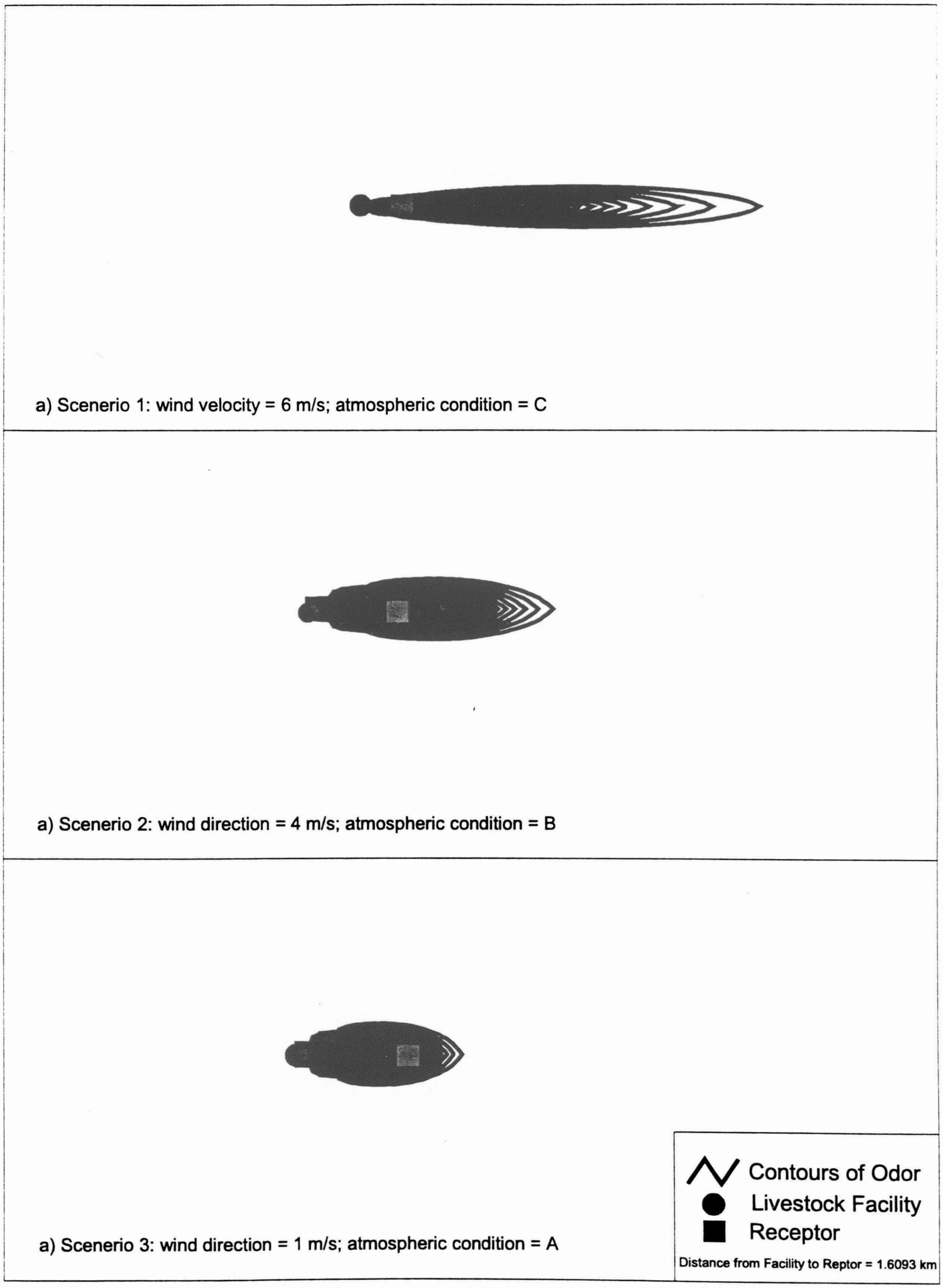

Figure 4. Odor plumes from three scenarios.

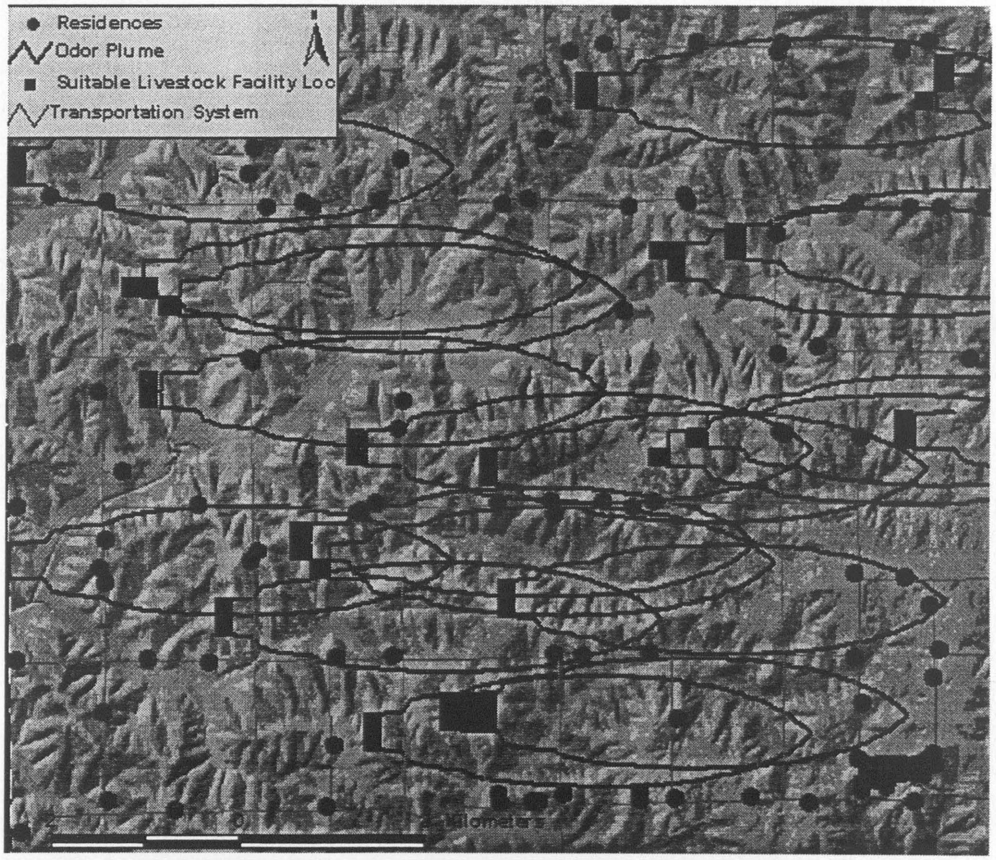

Figure 5. 2-D display of Gaussian odor plume draped on a DEM.

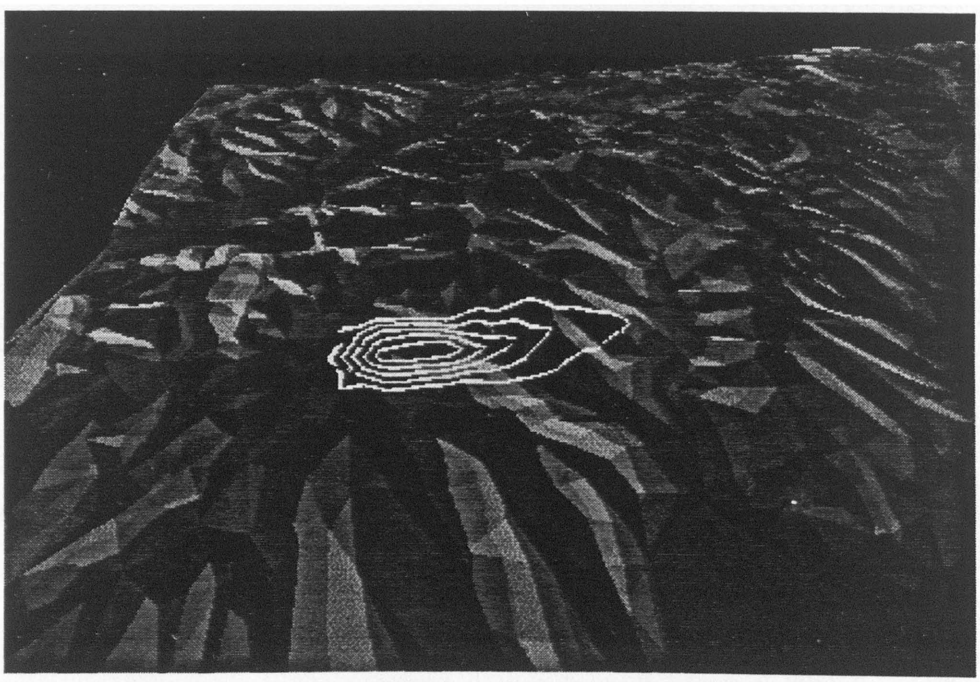

Figure 6. 3-D display of Gaussian odor plume draped on a DEM.

References

Bottcher, R.W., K.M. Keener, G.R. Baughman, R.D. Munilla, and K.E. Parbst. 1998. Windbreak Walls for Modifying Airflow and Emissions from Tunnel Ventilated Swine Buildings. In Proceeding of: Animal Production Systems and the Environment. Des Moines, Iowa. p. 639-644.

Bundy, D. S. and S. F. Hoff. 1998. The Testing Procedures and Results of Pit Additives Tested at Iowa State University. pp. 279-286. In Proceeding of: Animal Production Systems and the Environment. Ames, IA: Iowa State University.

Chen, Y.C. S.J. Hoff, and D.S. Bundy. 1998. Modeling and Evaluation of Dispersal Parameters for Odors from Agricultural Sources. Journal of Environmental Systems 26:27-39.

Environmental Systems Research Institute. 1998. ArcView GIS: The Geographic Information System for Everyone. Environmental Systems Research Institute, Redlands, CA.

Erickson, G. E., T.J. Klopfenstein, and C. T. Milton. 1998. Effects of Two Levels of Dietary Protein on Nitrogen Excretion and Waste Management in the Feedlot. pp. 67-72. In Proceeding of: Animal Production Systems and the Environment. Ames, IA: Iowa State University.

Grayson, R.B. I.D. Moore, T.A. McMahon. 1992. Physically Based Hydrologic Modeling. A Terrain-Based Model for Investigative Purposes. Water Resources Research 28:2639-2658.

Hasimoglu, S. 1998. Environmental Impact of Livestock Production Systems on Air Quality, Odor Nuisance, Global Warming and Health Concerns. pp. 649-654. In Proceeding of: Animal Production Systems and the Environment. Ames, Iowa: IA State University.

Iowa Agricultural Statistics. 1998. 1998 Iowa Agricultural Statistics. J.K. Sands and Holden (Editors). Des Moines, IA: Iowa Department of Agriculture and Land Stewardship.

Iowa Soil Survey, 1986. Soil Survey for Taylor County, Iowa. Washington, D.C.: U.S. Department of Agriculture.

Loehr, R.C. 1974. Agricultural Waste Management: Problems, Processes, and Approaches. New York, New York: Academic Press.

Lucas, R.D. and A.S. Tseng. 1995. Handbook of Air Pollution Control Engineering and Technology. pp. 317-336. J.C. Mycock, J.D. McKenna, L. Theodore (Editors). New York, NY:CRC Press, Inc.

Ortolando, L. 1997. Estimating Chances in Air Quality. In Environmental Regulations and Impact Assessment. pp. 516-547. New York:John Wiley and Sons.

Pasquill, F. 1961. The Estimation of the Dispersion of Windborne Material. Meteorological Magazine.

Tim, U.S. 1996. Emerging Technologies for Hydrologic and Water Quality Modeling Research. Transaction of the ASAE 39:465-476

Weichenthal, B., T. Holman, J. Schild, G. Koehler. 1998. Composting and Marketing of Beef Feedlot Manure in Western Nebraska. pp. 527-530. In Proceeding of: Animal Production Systems and the Environment. Ames, Iowa: Iowa State University.

CHAPTER 4. EVALUATING WATER QUALITY IMPACTS OF LIVESTOCK PRODUCTION PRACTICES

A paper to be submitted to the Journal of Soil and Water Conservation

I.M. Crawford and U.S. Tim

Abstract

Managing livestock waste in an environmentally sound way presents a major challenge to the livestock production industry as excessive amounts of manure can cause major environmental problems if not properly managed. The contamination of surface and subsurface water supplies due to non-point source pollution from livestock production has increased public concern in regards to large livestock operations. Thus, there is a need for tools and decision support systems (DSS) to guide the producer and decision-maker in choosing management practices that are environmentally sound and socially acceptable. Analysis of the environmental impacts of livestock production has increasingly depended on the use of emerging geospatial information systems as well as biophysical models to predict agricultural non-point source pollution. This paper presents a livestock production decision support system (LPRDSS) that integrates environmental, social, infrastructure, and political/regulatory geographic information systems (GIS) databases into a computer-aided DSS designed to assist decision makers in making rational choices in siting livestock facilities and applying manure. Specifically, this paper concentrates on the development and application of the biophysical modeling component of LPRDSS that supports the evaluation of water quality implications of livestock production. The biophysical model consists of the SWAT (Soil and Water Assessment Tool) water quality model that provide the tool to predict the impacts of land management on water, sediment, and agricultural chemical yields in large ungaged watersheds. Included in this paper is a discussion of the results of the SWAT model application to the Hundred and Two Mile River watershed located in Taylor County, Iowa are also presented to evaluate the effects of the site evaluation scenarios.

Introduction

Agricultural production, including crops and livestock, has been cited as the major source of non-point pollution of lakes, rivers, and estuaries (EPA, 1997). Sources of water contamination from livestock production include runoff from production facilities and manure application sites, leakage from manure storage facilities, and excessive manure applications. The high nutrient content of manure, specifically nitrogen and phosphorus, can have detrimental effects on both surface water and ground water quality. Nutrients not taken up by plants may be lost to the environment, contributing to surface and groundwater contamination through runoff and leaching. Proper selection of sites for livestock facilities and land areas for manure application offer a cost-effective and efficient solution for minimizing the effects of livestock production on the environment. Due to the growing number of large livestock operations in the United States, there are increasing concerns over the potential environmental impacts of production practices. Odor pollution, fish kills from lagoon seepage and manure runoff, microbial pathogen contamination, and nitrate contamination of drinking water supplies are the most pervasive environmental pollution problems from concentrated animal production facilities. Section 319 of the Clean Water Act directs each state to conduct an in-depth assessment of non-point source pollution of ground and surface waters, and to develop management plans to mitigate potential impacts. At the state level, regulations have been passed to reduce non-point and point sources of water pollution. The majority of these regulations are targeted towards livestock production. For example, Iowa has established setback distances between large hog operations and neighbors, depending on landuse and the total body weight of pigs. Many other states, including Kansas, North Carolina, Illinois, Missouri, Oklahoma, and South Dakota, have also passed regulations to control non-point source pollution from agriculture.

Computer simulation models offer a method for assessing the environmental effects of agricultural management practices. A number of computer simulation models have been developed to assess impacts of crop and livestock production on the environment (Arnold et al., 1990; Williams et al., 1984; Schaffer et al., 1991; Houlahan et al., 1992; Beasley et al., 1980; Young et al., 1989; and Beven and Kirkby, 1979). These simulation models provide a cost-effective alternative for evaluating potential implications of many different agricultural practices, for testing hypothetical scenarios of land use, and to determine the "best case scenario" for resource management decision-making. Because of the large volumes of data required by simulation models, many attempts have also been made to reduce the time requirement for data input through the use of geographic information systems (GIS). Since many factors affecting environmental quality have a spatial dimension, extracting relevant input data information from a GIS appears to be a viable option. In water quality modeling, GIS provides a powerful tool to manipulate, organize, analyze, and display large amounts of disparate data. According to Tim (1996), the successful modeling of agricultural watersheds for non-point source pollution control is dependent upon the ability of scientists and resource managers to mange and manipulate large volumes of input data, and to summarize and display simulation results in a variety of forms. When a GIS is used with a water quality simulation model, a highly sophisticated watershed ecosystem management tool can be derived.

Integrating simulation models, GIS, and environmental databases into a comprehensive decision support system offers yet a more enhanced tool for planning and developing effective livestock production systems that are profitable and environmentally sensitive. One advantage of a DSS is that data and models can be made responsive to a wide a range of spatial and temporal scales. In general, a DSS is designed to enable decision-makers to utilize data and models to solve unstructured problems. For example, selecting a suitable site for planning livestock production systems is typically an ill-structured problem (Arentze et al., 1996), as there are many conflicting objectives and uncertainties involved in the analysis. Such analysis can be influenced by many conflicting goals and objectives, such as the need to maximize profitability of the livestock enterprise and to minimize potential environmental (air and water) impacts. In addition, a DSS allows the resource manager or decision-maker to incorporate these conflicting objectives in a consensus-based framework to determine an equitable and sustainable management option (Armstrong et al., 1991; Densham, 1991).

Proper site planning of livestock production facilities and selection of suitable land areas for manure application can alleviate adverse impacts on the environment. However, because livestock site planning is typically an ill-structured problem, as there are several types of uncertainty on the consequences of optional actions, a robust and comprehensive decision support system is generally required. This research addresses the need for a DSS that allows resource planners and decision-makers to plan and implement livestock production practices that are environmentally sound and socially acceptable. Specifically the research developed LPRDSS (Livestock PRoduction Decision Support System), a microcomputer-based DSS that allows users to evaluate different site selection options, incorporate different management objectives and criteria, and identify sites and management options that are sustainable. Other potential applications of LPRDSS include: (1) selecting optimal sites for locating livestock production facilities at various spatial scales; (2) determining socially acceptable and environmentally sound land areas for animal manure application; (3) evaluating the impacts to fragile ecosystems and resources from manure application; and (4) identifying the social implications of a particular livestock facility in terms of its contribution to odor nuisance complaints from neighbors. In this paper, brief details of LPRDSS are presented and emphasis is placed on the development and application of the biophysical modeling components that can be used to assess water quality implications of large hog confinement operations. The paper is structured in several sections as follows. First the components of LPRDSS are presented to assist understanding of the models and databases used in the research. Then the biophysical modeling using the SWAT hydrologic and water quality model is described. This is followed by an example application of the biophysical model to a watershed located in Taylor County, Iowa.

Methods and Materials

Figure 1 shows the conceptual structure and components of LPRDSS, which consists of three primary modules: a multi-criteria site selection module, a water quality module, and an odor dispersion/diffusion module. As previously indicated, LPRDSS was developed primarily to provide a tool for land managers and decision-makers to locate livestock production areas that will have a minimal impact on air and water quality. The suitability of a land area for locating a livestock operation or the land application of manure is determined using a multi-criteria site evaluation model. Land areas identified as suitable for siting a facility and for manure application are than evaluated for their

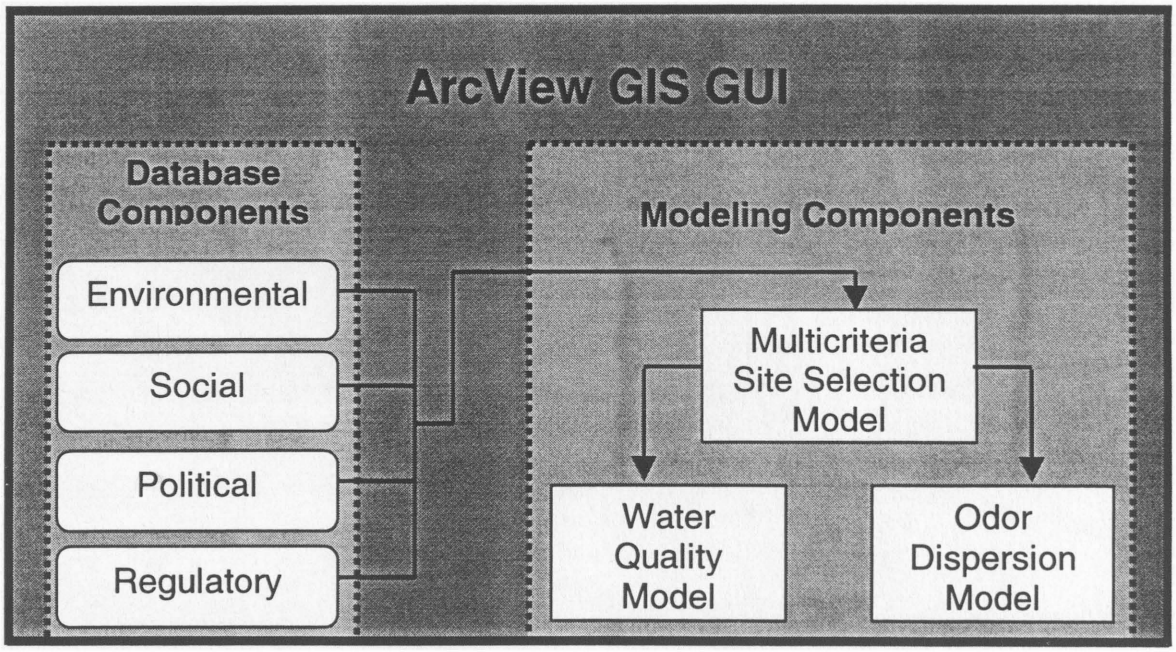

Figure 1. Components of the Livestock PRoduction Decision Support System (LPRDSS).

air and water pollution impacts through the use of the SWAT biophysical module and a terrain-based Gaussian odor dispersion/diffusion module. In the following sections, a brief description of the site evaluation and biophysical modules are presented.

Multi-Objective Site Evaluation Model

The multi-objective site evaluation model follows the methodology described by Jain et al. (1995). The model consists of a spatial weighting scheme of 14 different environmental, social, political, and regulatory variables that influence livestock facility siting as well as land areas to apply manure. Representing these variables are a set of site selection criteria, including: distance from streams, roads, lakes, wetlands, and wells (agricultural drainage and drinking); proximity to residences, sinkholes, incorporated and other public areas, and landmarks such as churches and schools; topographic features and physical characteristics, such as land slope and aspect; and environmental factors such as soil drainage, soil permeability, flood potential, and land cover. Each variable is subdivided into categories based on regulatory and/or scientific criteria, and each criterion is subsequently assigned a weight based on its suitability. Table 1 lists some of the variables, criteria, and criteria ratings used in LPRDSS for siting livestock facilities.

The multi-objective site evaluation model is implemented either as an exclusive (or absolute) criteria that eliminates sites from consideration on the basis of environmental, social, or political regulatory restrictions or as a non-exclusionary (or relative) criteria that ranks suitable land units according to their relative ranking computed by a scaled composite suitability score. In the absolute criteria, a site is automatically eliminated if it fails to meet a specified criterion for each regulatory or physiographic restriction such as slope, distance to streams, and soil drainage. In the relative ranking option, each criterion is ranked using an appropriate rating scheme. For example, the proximity to stream criteria is divided into six categories based on numerical values of distances, and a factor score or rating is then assigned to each category. A site having a distance greater than 400 m from a stream receives an appropriately higher rating than a site that is only 100 m from the stream. A weight is then assigned to represent the importance of stream proximity to the overall suitability of the site. The suitability or desirability of a site or land unit *i* for a given criterion *j* can be determined by using the following equation:

$$S_{ij} = \sum_{j=1}^{N} f_{ij} w_j \tag{1}$$

in which:

$$f_{ij} = \begin{bmatrix} f_{i1} & \cdots\cdot & f_{iN} \\ \cdot & \cdot & \cdot \quad \cdot \\ f_{1j} & \cdots\cdot & f_{ij} \end{bmatrix} \tag{2}$$

$$\Sigma w_j = w_i + w_2 + w_3 ... + w_j \tag{3}$$

where S_{ij} is the composite suitability score of the land unit, f_i ($0 \le f_i \le 10$) is the factor score, or rating, or numerical score of a variable, w_j (<100) is the assigned weight of the criterion, and *N* is the number of criteria assumed important to the site selection process. The maximum cumulative suitability score for a land unit is 1000, which is re-scaled to a value ranging from 0 to 100.

The above equations were used both to assess the suitability of a land area for siting a production facility and for identifying those land areas that are suitable for manure application on the basis of modified criteria, weights and factor score. Figures 2a and 2b show the user interface, menu options, and dialog boxes designed to facilitate user interaction and navigation of site selection component of LPRDSS. Modeling capabilities provided by ArcView GIS Spatial Analyst extension were used to calculate S_{ij}. Several scripts written in Avenue facilitated calculations of the values in the cumulative suitability grid. The output from the site selection can be visualized in map or table format.

Table 1. Summary of some criteria ratings important to siting a livestock production facility.

Soil Drainage		Land Slope		Public Areas/Towns	
Category	Rating	Category	Rating	Category	Rating
Well Drained	10	0%-2%	10	< 420 m	0
SW Mod Well Dr.	9	2%-5%	8	420 – 500 m	2
Mod. Well Drained	7	5%-14%	6	500 –600 m	6
SW Poorly Drained	3	14%-35%	2	600 – 800 m	9
Poorly Drained	0	>35%	0	> 800 m	10

Soil Permeability		Lakes/Wetlands/Stream		Road Proximity	
Category	Rating	Category	Rating	Category	Rating
< 0.15 cm/hr	0	< 60 m	0	< 210 m	0
0.15 – 0.51 cm/hr	2	60 – 100 m	2	210 m – 402 m	6
0.51 – 1.52 cm/hr	4	100 – 200 m	6	402 m – 804 m	10
1.52 – 5.10 cm/hr	8	200 – 300 m	8	804 m – 1609 m	9
5.10 – 15.2 cm/hr	9	300 – 400 m	9	1609 m – 3218 m	6
> 15.2 cm/hr	10	> 400 m	10	> 3218	0

Agricultural and Drinking Wells		Flood Frequency		Landuse	
Category	Rating	Category	Rating	Category	Rating
< 160 m	0	Frequent	0	Urban, Industrial,	
160 – 200 m	2	Common	2	Commercial,	0
200 – 300 m	6	Occasional	7	Forest, & Water	
300 – 400 m	8	Rare	9		
> 400 m	9	None	10	Other	10

Once the cumulative suitability score of a land area has been evaluated, it is checked against the minimum contiguous land area requirement stipulated for that production system (see Table 2). The minimum contiguous area criteria is established to ascertain that the land area identified is large enough to accommodate livestock housing needs as well as areas to construct lagoons, if needed. Overall, the site selection model provides the user with the capability of evaluating various livestock production strategies. The strategies are also summarized in Table 2.

Biophysical Modeling

The biophysical modeling component of LPRDSS is intended to evaluate the soil and water quality implications of different livestock operations and the manure/fertilizer management practices related to livestock production. In this component, the potential water quality impact of land application of manure is assessed by the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1993), a process-based simulation model developed at the Blackland Research Center, Temple, Texas. Specifically, SWAT was developed primarily to improve predictions of the impacts of agricultural land management on water quality in ungaged watersheds and basins (Arnold et a.l, 1998). The model provides users with the capability to evaluate and compare the effectiveness of alternative land use and animal manure management practices. An ArcView GIS – SWAT interface

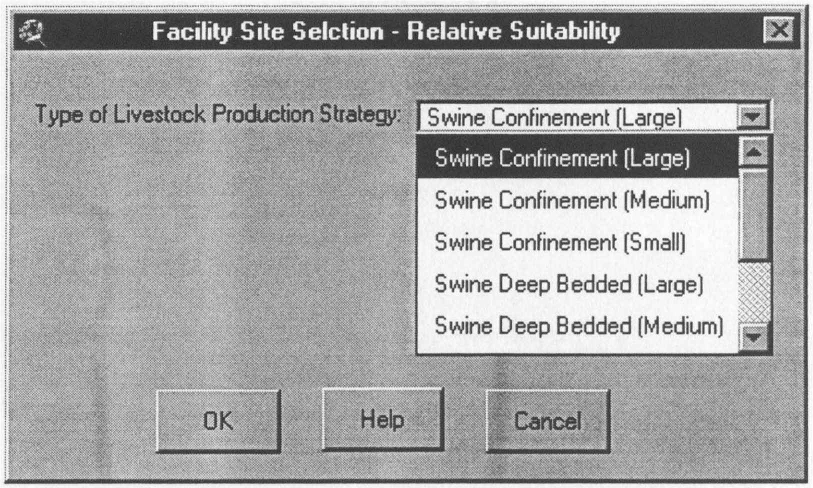

Figure 2. The dialog box in the Facility Site Selection DSS where the user can select a production strategy for the detailed analysis.

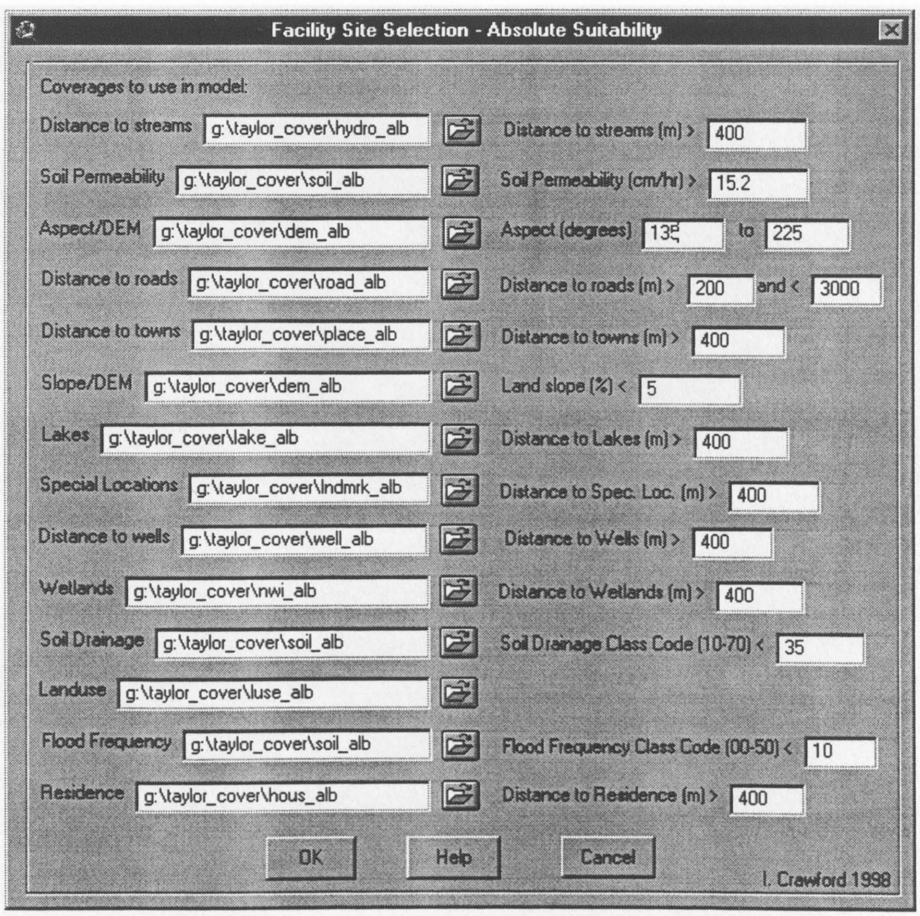

Figure 3. Layout of LPRDSS screen for identifying suitable production sites on the basis of absolute or exclusionary option.

Table 2. Livestock production strategy contiguous land area requirements.

Production Strategy	Small	Medium	Large
Swine Confinement	100 sows 0.8 ha	250 sows 1.2 ha	1,000 sows 4 ha
Swine Deep-bedded	100 sows 1 ha	250 sows 1.2 ha	500 sows 2 ha
Swine Pasture	50 sows 3.6 ha	100 sows 7.1 ha	250 sows 19 ha

(Di Luzio et al., 1997) has been incorporated into the LPRDSS to enhance the use of existing or future GIS databases for modeling and to assist in the input of data. Once the user has selected suitable sites for locating livestock facilities and the land areas for manure application, the SWAT model then provides the framework for the prediction of the nutrient and sediment yields from manure application areas. It also allows the analysis of 'what-if' scenarios related to livestock production and manure management. Alternative scenarios, such as imposing limits on nutrient applications can be evaluated and compared with the baseline practice to elucidate the effectiveness of the particular practice.

Generally, SWAT allows a watershed to be divided into hundreds or thousands of grid cells or subbasins preserving the spatially distributed parameters of the entire basin. Each subbasin is assumed to be a hydrologically homogenous region. The model consists of eight sub-components for representing: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. The hydrology model is based on the water balance equation:

$$SW_t = SW + \sum_{t=1}^{t} (R_t - Q_t - ET_t - P_t - QR_t) \tag{4}$$

where SW is the soil water content minus the 15-bar water content, t is time in days, and R, Q, ET, P, and QR are the daily amounts of precipitation, runoff, evapotranspiration, percolation, and return flow, respectively. Since the model maintains a continuous water balance, complex watersheds can be subdivided to reflect differences in ET for various crops and soils. Thus, runoff and chemical transport are predicted separately for each subbasin and routed to the watershed outlet to obtain the cumulative sediment, nutrient, or chemical runoff for the entire watershed. Dividing a watershed into subbasins increases the accuracy of the output results and provides a better physical description of the water balance. SWAT predicts the following hydrologic parameters: surface runoff volume, percolation, lateral subsurface flow, ground water flow, evapotranspiration, snow melt, and transmission losses and adjusts for ponds and reservoirs.

In SWAT, sediment yield is computed for each subbasin by using the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977):

$$Y = 11.8 \left(V q_p \right)^{0.56} (K)(C)(PE)(LS) \tag{5}$$

where Y is the sediment yield from the subbasin, V is the surface runoff column for the subbasin (in m^3), q_p is the peak flow rate for the subbasin (in m^3s^{-1}), K is the soil erodability factor, C is the crop management factor, PE is the erosion control practice factor, and LS is the slope length and steepness factor. The agricultural management component of SWAT provides submodels that simulate tillage systems, the application of irrigation water, fertilizer, pesticides, and grazing systems. Specifically, SWAT allows fertilizer applications to be scheduled by the user or automatically applied by the model. The former option requires the user to input the application date, total amount of N and P, fraction of organic and inorganic N and P, and the soil layer of application. The model than adds the amount of fertilizer to the proper nutrient pool (organic and inorganic) and to the specified soil layer. Organic N runoff loss is calculated from the total concentration of organic N in the sediment yield reaching the basin outlet. When NO_3-N and soluble P enters a stream it is considered a conservative material and routing is accomplished by adding the yields from all subbasins to determine the overall watershed yield. Amounts of NO_3-N contained in runoff, lateral flow, and percolation are estimated as the products of the volume of water and the average concentration. Leaching and lateral subsurface flow in lower layers are treated with the same approach used in the surface soil layer except surface runoff is not considered. The loading function estimates the daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield, and the enrichment ratio. Because P is mostly associated with the sediment phase, the soluble P runoff is predicted using labile P concentration in the top soil layer, runoff volume, and a partitioning factor. Sediment transport of P is simulated with a loading function as described in organic N transport. Crop use of N and P is estimated with the supply and demand approach.

Previous applications of SWAT have shown promising results in simulating hydrologic functions. Srinivasan et al. have successfully used SWAT to simulate hydrologic and water quality functions in Texas including the Rio Grande/Rio Bravo Basins (1997), Seco Creek Watershed (1994), and the Naches River Basin (1993). Other researchers and scientists (Cho et al., 1995; Rosenthal et al., 1995; and Manguerra and Engel, 1998) have had similar success with the SWAT model in other areas of the United States.

The spatial databases needed for the SWAT model includes land management inputs such as fertilizer use, crop rotations, tillage operations, planting and harvesting dates, and pesticide application rates. As part of the site selection module, amount of manure produced by the scenario is estimated for the management area (county or watershed) using the number of facility sites and the land area suitable for manure application. The yearly amount of animal manure produced by livestock operations and its nutrient composition as used in the simulations are summarized in Table 3. The SWAT model also requires several physical characteristics of the watershed and its subbasins. These include: climatic data (e.g. precipitation, temperature, humidity); soil properties (e.g. bulk density, content); topography (e.g. slope, length of slope); land cover; channel morphology (e.g. channel length, channel slope, side slope, width and type), Mannings (n) roughness coefficients; USLE k factors for each landcover type; and hydrogeological variables. The input data required for the SWAT model, either for each subbasin or the entire basin can be generated, organized, and manipulated by a customized user interface designed as part of the general ArcView GIS interface.

Table 3. Average nutrient concentrations in the applied manure.

Production Strategy	Small	Medium	Large
Swine Confinement	100 sows	250 sows	1,000 sows
Mineral N-NO3-N 0.566	2,080,236 litres	5,319,818 litres	21,279,270 litres
Mineral P 0.85	1,040,118 kg	2,659,909 kg	10,639,635 kg
Organic N 0.75			
Organic P 0.15			
Ammonium NO_3 0.25			
Swine Deep-bedded	100 sows	250 sows	500 sows
Mineral N-NO3-N 0.012	813 tonnes	2,030 tonnes	967 tonnes
Mineral P 0.85	812,900 kg	2,030,300 kg	4,631,300 kg
Organic N 0.84			
Organic P 0.30			
Ammonium NO_3 0.16			
Swine Pasture	50 sows	100 sows	250 sows
Mineral N-NO3-N 0.012	193 tonnes	387 tonnes	967.1 tonnes
Mineral P 0.70	193,200 kg	387,400 kg	967,100 kg
Organic N 0.50			
Organic P 0.15			
Ammonium NO_3 0.50			

Example Application

In the research, LPRDSS was used to assess suitable areas in Taylor County, Iowa (Figure 4) for siting large (1000) sow confinement operations and to evaluate water quality impacts of production practices within the Hundred and Two Mile River watershed located in the county (Figure 5). This example application is intended to demonstrate the relationship between the various modeling components and to evaluate the watershed water quality problems that can result from various site selection options.

Taylor County has a total land area of 135,168 ha, of which 132,880 ha of land were in farms in 1997 (Iowa Agricultural Statistics, 1998). Bedford, the county seat, is situated about 192 km southwest of Des Moines. Taylor County is primarily rural and has very few industries. About 41,712 ha (or 31%) of Taylor County meets the U.S. Department of Agriculture soil requirements for prime farmland (NRCS, 1996). Nearly all of this prime farmland is used for crops, which consist primarily of corn and soybeans. Crops grown on this land account for an estimated 50 to 60% of the county's total annual agricultural income. Like much of the U.S. Midwest, the farms in Taylor County have been increasing in size and decreasing in number. Between 1981 and 1997, the number of farms decreased from 980 to 746 but the average farm size increased from 138 to 156 hectares. (Soil Survey, 1986; Iowa Agricultural Statistics, 1998). Livestock production consists of swine, beef, poultry, and sheep integrated with the cropping systems. Approximately 71,500 hogs and pigs were produced in the county in 1997.

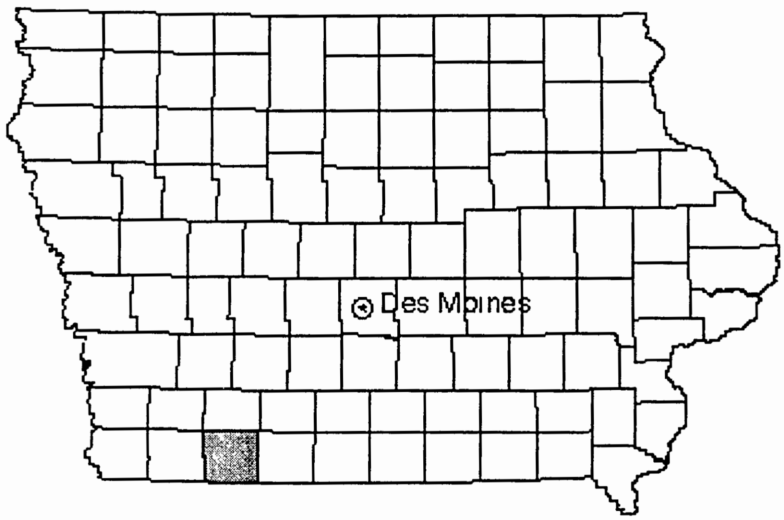

Figure 4. Location of Taylor County in Iowa.

The total annual precipitation for Taylor County is 932 mm, of which 660 mm usually falls between April and September. Average temperature during the summer is 23°C, while winter temperatures average about –3°C. The average relative humidity in mid-afternoon is about 60%. Humidity is higher at night, and the average at dawn is about 80%. The prevailing wind is from the northwest, with an average wind speed of about 21 km/hr during the spring, and sometimes gusting to about 64 km/hr.

The Hundred and Two Mile River watershed located in Taylor County was chosen for the evaluation of the impact of manure management practices on water quality. The watershed has a land area of 274 km^2. There are five dominant soil types in the watershed, including: Lamoni, Nira, Sharpsburg, Clearfield, and Adair (Figure 6). The soils of the nearly level upland divides are poorly drained. The loess soils of the gently sloping upland ridges are moderately well drained to somewhat poorly drained and the soil located in the flood plains are typically poorly drained. Subsurface drainage systems are present in almost all agricultural fields. There are 72,865 ha of corn and 11,417

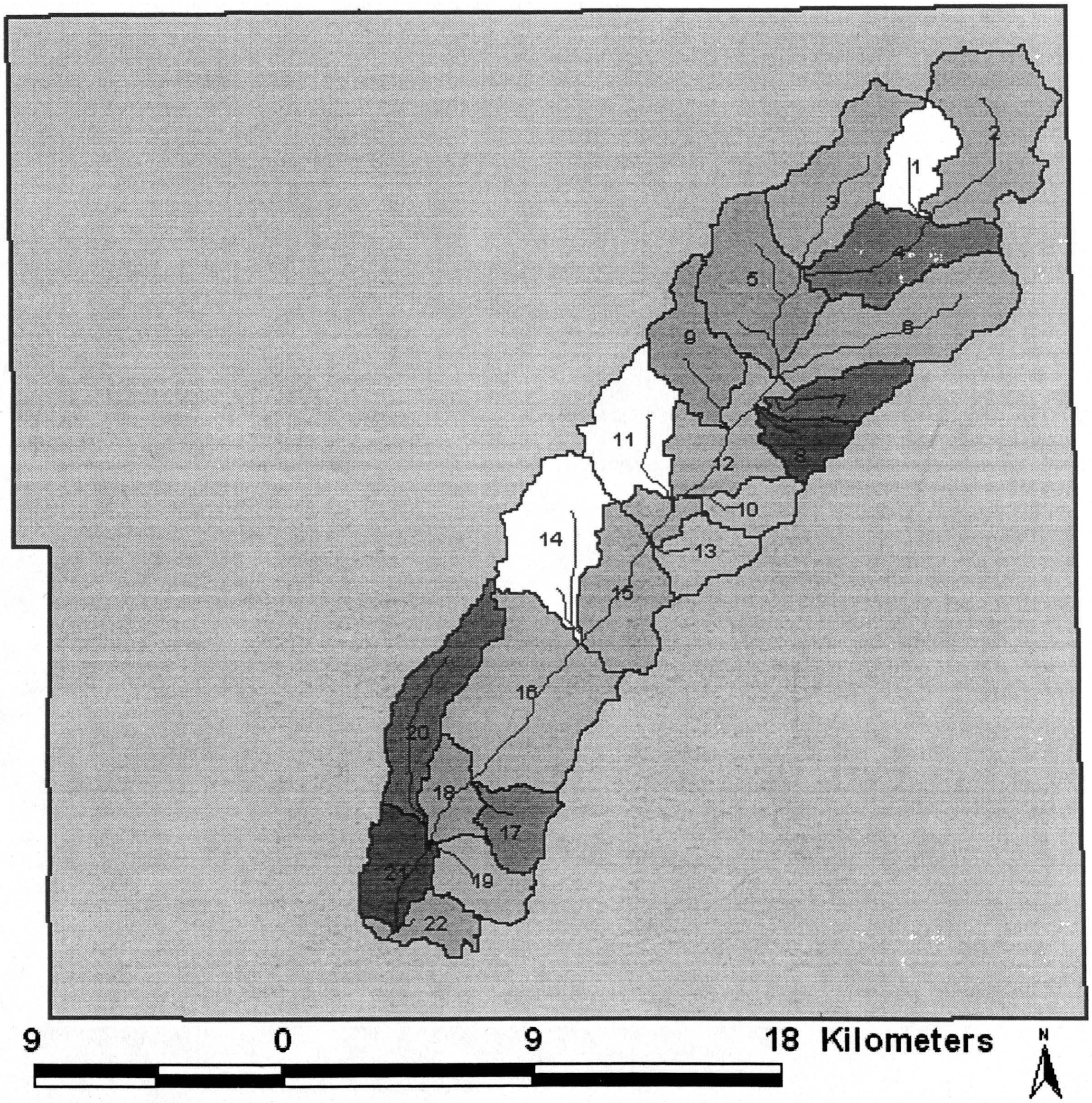

Figure 5. Location of Hundred and Two Mile River watershed in Taylor County, Iowa. The watershed and subbasins are delineated with the SWAT – ArcView GIS interface.

ha of soybeans in the watershed, and the remaining land cover is comprised of forest, urban, rangeland, and small grains (Figure 7). There are approximately 148 km of perennial and 49 km of intermittent streams in the watershed. The towns of Bedford, Conway, Sharpsburg, and Lenox are located in the watershed. Bedford obtains its water supply from the Platte River watershed and some from the Hundred and Two Mile River. The other towns are supplied water from outside the watershed by rural and city water associations.

In this study, the site evaluation and biophysical modeling components of LPRDSS were used to select suitable sites for livestock production facilities and manure application and to evaluate different manure management scenarios with respect to nitrogen (N) and phosphorus (P)

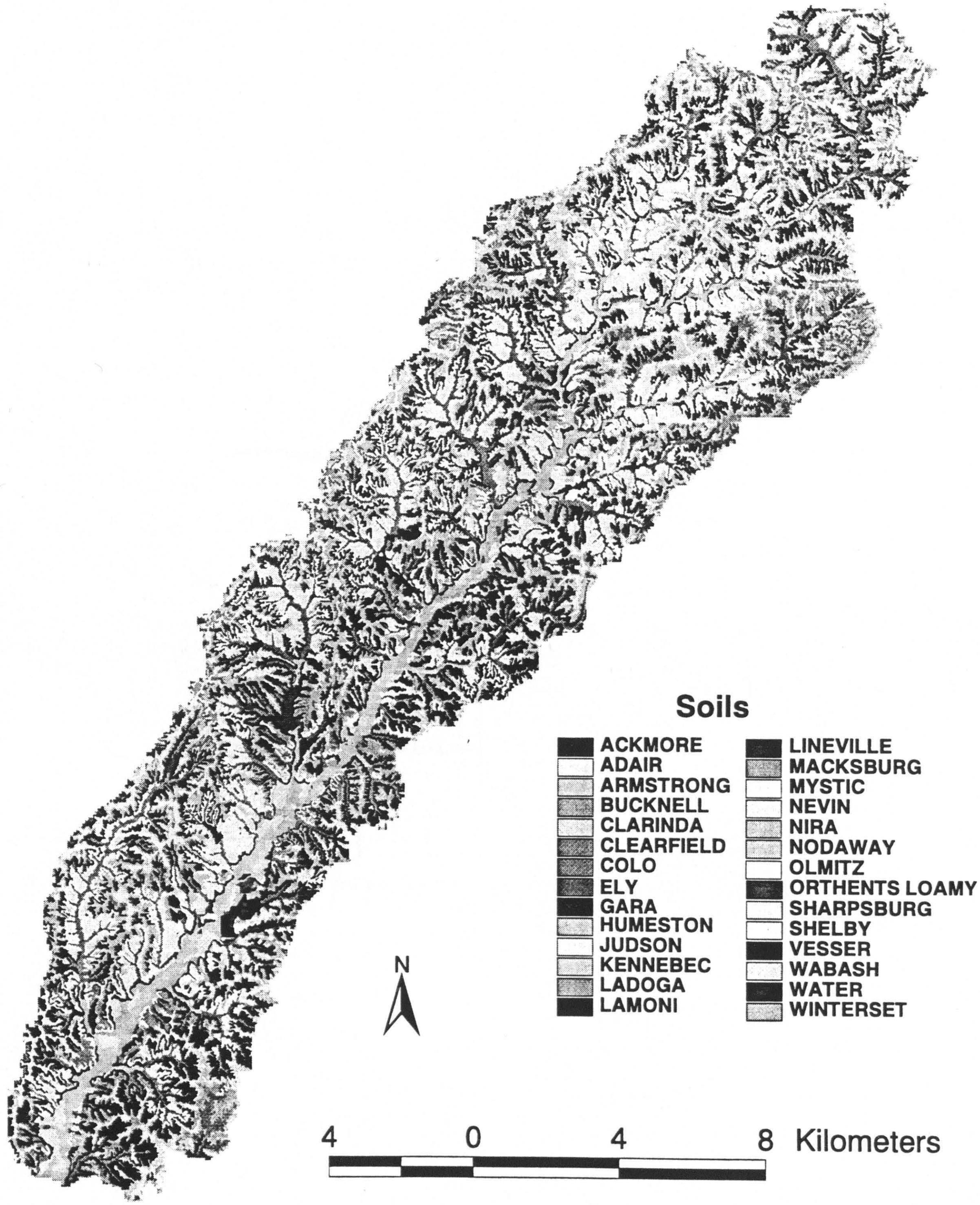

Figure 6. Soils in the Hundred and Two Mile River watershed in Taylor County, Iowa

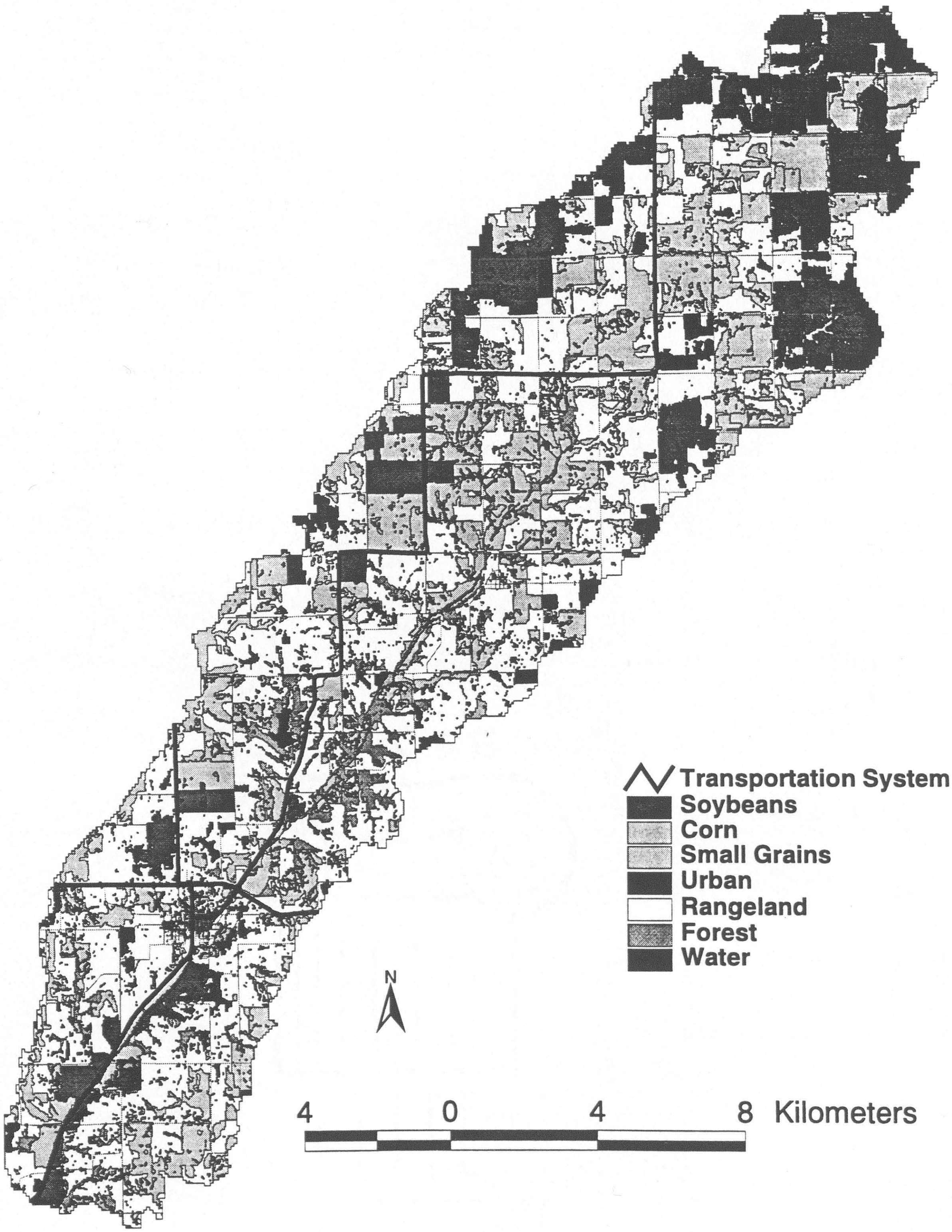

Figure 7. Land cover in the Hundred and Two Mile River watershed in Taylor Couny, Iowa.

concentrations at the watershed outlet. Table 4 summarizes the two livestock production strategy scenarios evaluated with the LPRDSS. Both scenarios evaluate the land area in Taylor County for locating large (1,000 sow) confinement operations given various environmental, social, and regulatory constraints. In scenario 2, environmental constraints related to water resources were tightened for locating livestock facilities. For example, proximity of potential sites to streams, lakes, wetlands, and wells was increased from 400 m to 750 m. Figures 8 and 9 show the corresponding suitable land areas for scenarios 1 and 2, respectively. As expected, more land area was suitable for siting large-scale swine operations when constraints were less stringent. For example, in scenario 1, about 199 sites, or 1,257 ha (or 0.93% of the land base) of the total land area in the county were found to be suitable and approximately 55 sites, or 263 ha, in the Hundred and Two Mile River watershed were found to be suitable for siting large confinement operations. However, under scenario 2, only 53 similar swine confinements can be located within the county (or 263 ha of the land base) and 5 sites (or 28 ha of the land base) in the Hundred and Two Mile River Watershed.

Table 4. Livestock production scenarios for Taylor County, Iowa evaluated with LPRDSS

	Scenario 1		Scenario 2	
Criterion	Facility	Manure	Facility	Manure
Distance to strms./lakes/wetl.	> 400 m	> 400 m	> 750 m	> 400 m
Distance to roads	100- 3000m	100 - 3000m	100 - 3000m	100 - 3000m
Distance to incorp. areas/resid.	> 400 m	> 400 m	> 400 m	> 400 m
Distance to special locations	> 400 m	> 400 m	> 400 m	> 400 m
Distance to wells	> 400 m	> 400 m	> 750 m	> 400 m
Aspect	135º - 225º	135º - 225º	135º - 225º	135º - 225º
Slope	< 5%	< 5%	< 5%	< 5%
Landuse		= Corn		= Corn
Soil permeability	> 15.2 cm	> 15.2 cm	> 15.2 cm	> 15.2 cm
Soil drainage	> Mod Well	> Mod Well	> Mod Well	> Mod Well
Flood frequency	Slight/None	Slight/None	Slight/None	Slight/None

The site selection module was also used to identify suitable land areas for manure application given the constraints outlined in Table 4. Approximately 5,223 ha (or 3.86% of the land area) in the county was identified to be suitable for manure application given the criteria specified under the scenario and about 1,028 ha (or 0.76% of the land area) in the Hundred and Two Mile River watershed (Figure 10).

The SWAT model was used to assess the water quality impacts of implementing each site selection scenario (implementing 55 sites (scenario 1) or implementing 5 sites (scenario 2)) in the Hundred and Two Mile River watershed. The water quality impacts of applying 220 kg/ha of N fertilizer and 60 kg/ha of P fertilizer (scenario 3) were also analyzed with the SWAT model. The watershed boundary was delineated from a USGS DEM and other necessary data were extracted from the GIS databases including soils, current landcover and climatic data. Nutrient content of the manure was estimated from values previously discussed (see Table 3). Approximately 569,241 kg/ha

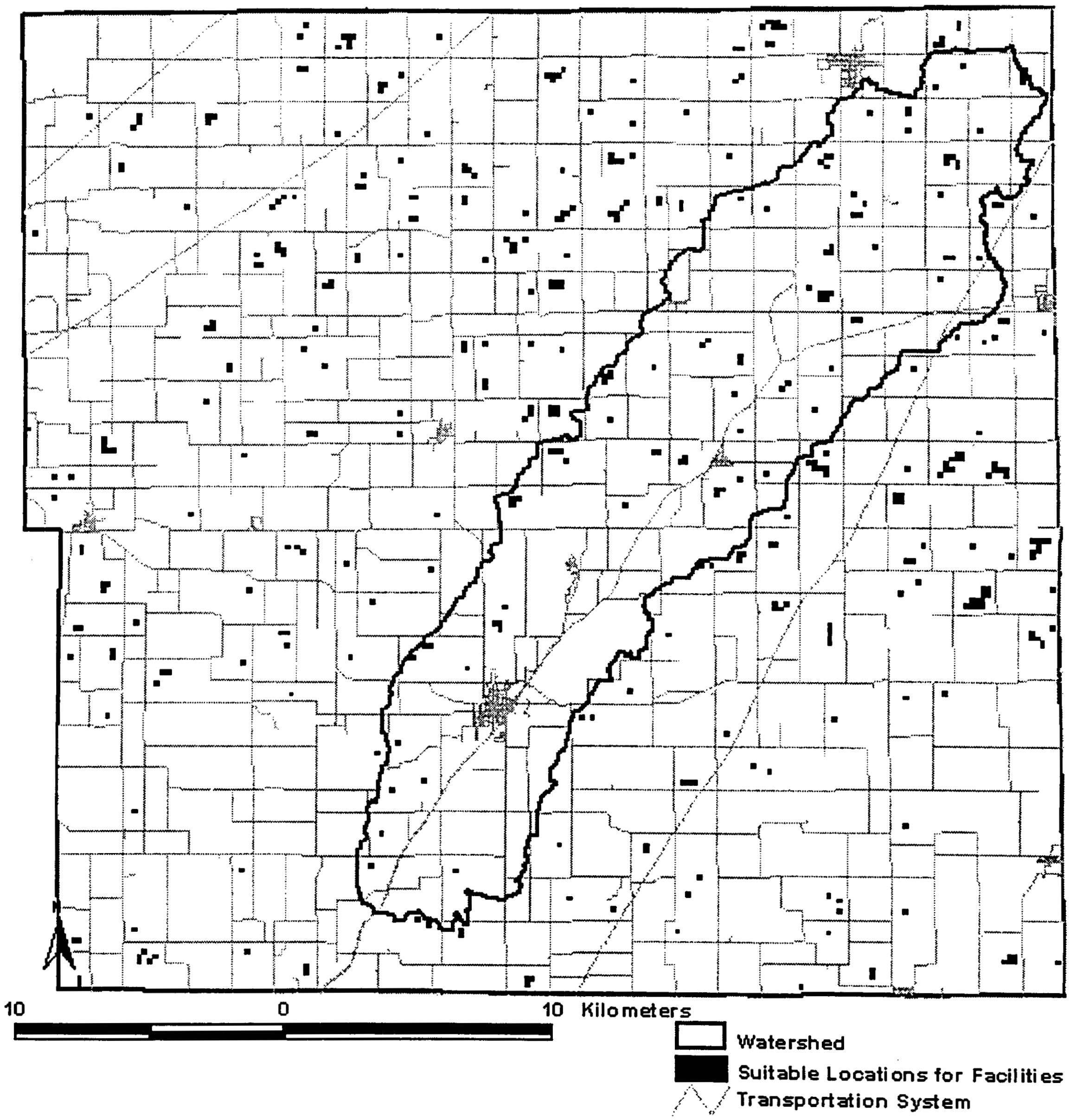

Figure 8. Location of suitable areas for siting large-scale swine confinement facilities in Taylor County, Iowa using criteria from scenario 1.

of manure was applied in the watershed under scenario 1 and about 51,749 kg/ha was applied under scenario 2. Simulation results of scenarios 1, 2, and 3 are shown in Figure 11.

To evaluate the effect of land management changes on water quality, the watershed land cover was changed from corn to soybeans, and soybeans to corn was implemented. The landuse coverage used for the site selection module is based on 1992 data when the watershed produced 72,856 ha of corn and 11,417 ha of soybeans. Therefore, using the assumption all crops would be converted from corn to soybeans and manure would be applied only to land areas with corn, it would be reasonable to assume there would be fewer sites available for the land application of manure. This change in land cover would only affect manure application site selection. Figure 12 shows the manure application site evaluation results of modifying cropping patterns in the county. Approximately 1,328 ha are suitable for land application of manure when crops are rotated. This is 25.4% less land area than before changing the cropping land cover. Using the same results from the facility site evaluation in scenarios 1 and 2 (199 and 48 facilities, respectively), nutrient transport to the watershed outlet was simulated. Approximately 440,648 kg/ha of manure was applied under scenario 1 and 40,058 kg/ha of manure was applied under scenario 2.

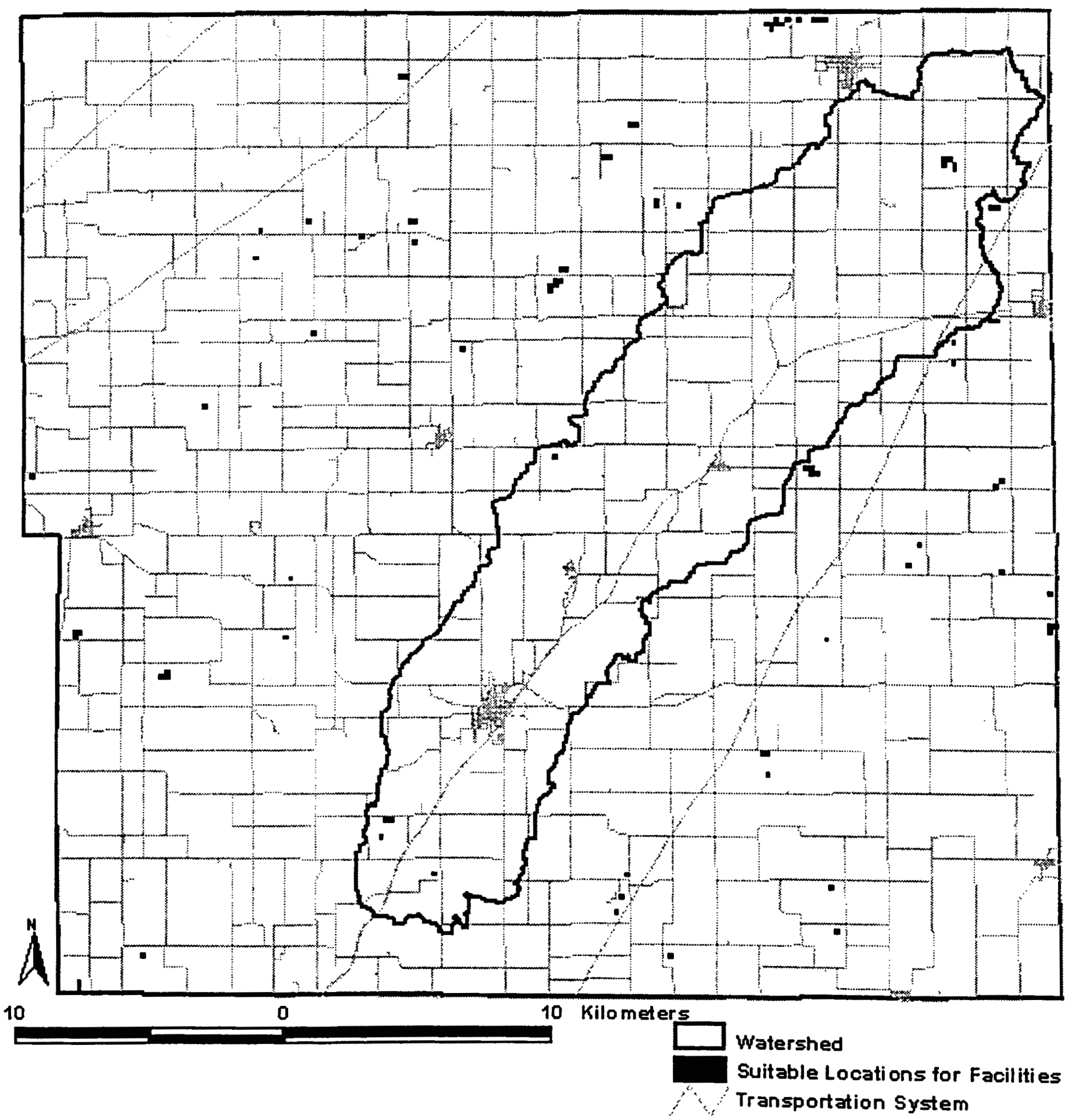

Figure 9. Location of suitable areas for siting large-scale swine confinement facilities in Taylor County, Iowa using criteria from scenario 2.

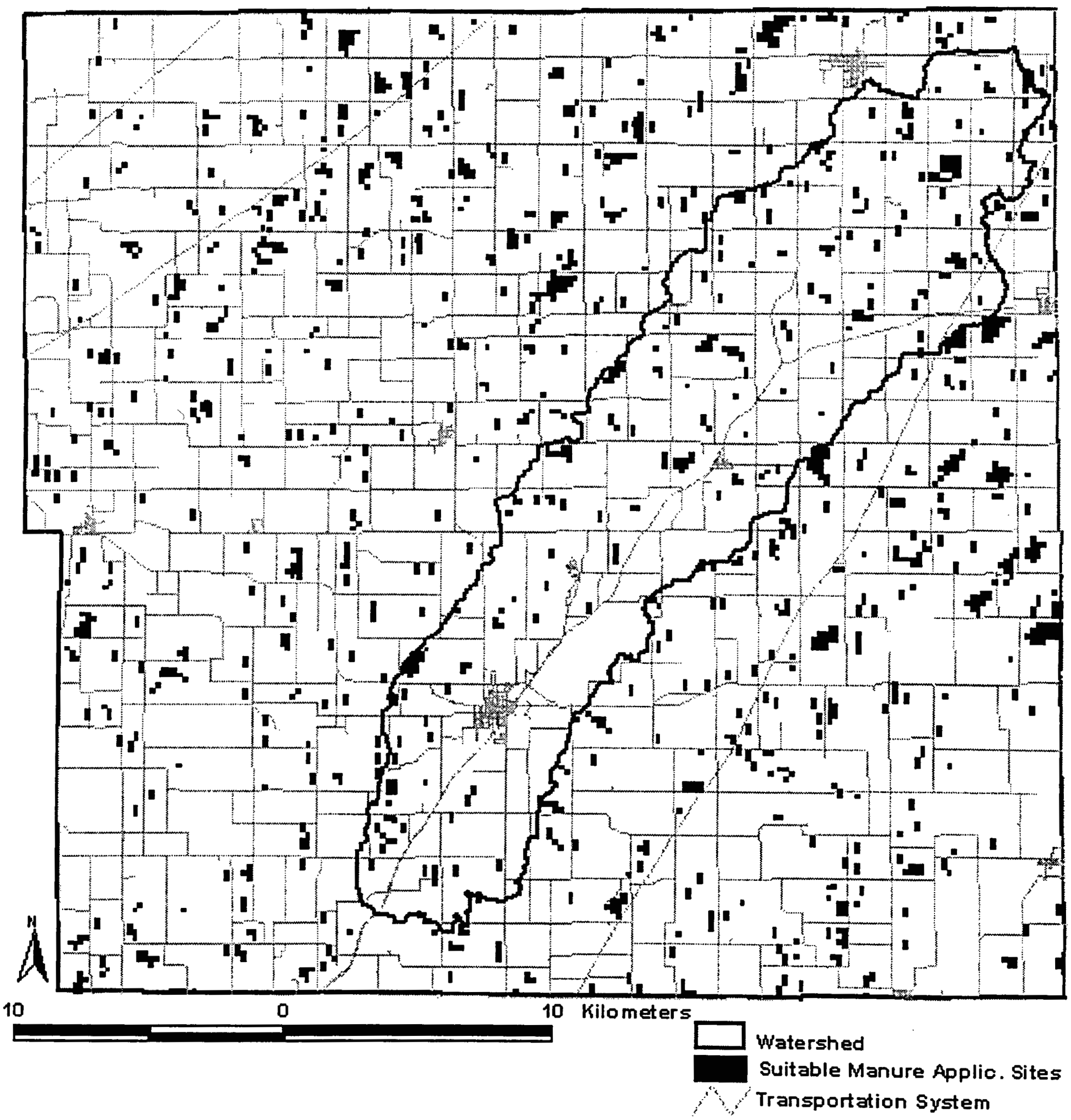

Figure 10. Suitable locations in Taylor County, Iowa for land application of manure under scenario 1 and 2.

Summary and Conclusion

This paper discusses a DSS developed to allow rapid delineation of suitable livestock production sites and to assess the environmental impact of production practices on water quality. The selection of suitable areas for livestock facilities and manure application is a complex and ill-structured process. Through the use of the GIS-based LPRDSS, resource planners and decision-makers are able to manipulate, analyze, and visualize large amounts of environmental data while addressing multiple objectives that influence the livestock site selection process. A biophysical

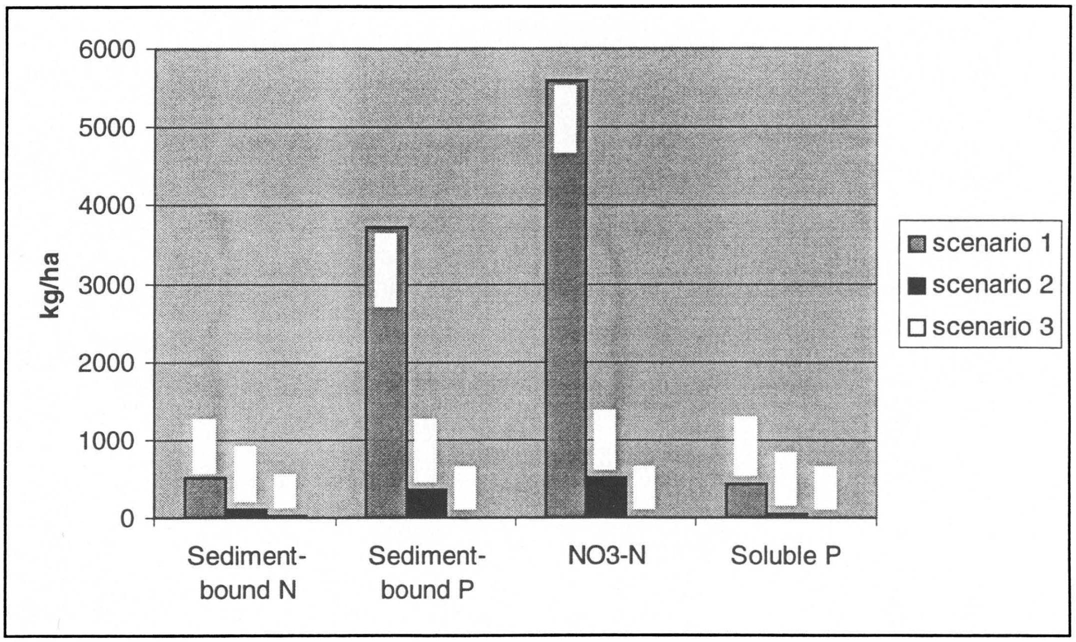

Figure 11. SWAT results for scenario 1 and 2 in the Hundred and Two Mile river watershed in Taylor County, Iowa.

component of LPRDSS evaluates the soil and water quality implications of different livestock production and manure/fertilizer management practices. In this component of LPRDSS, the potential water quality impact of land application of manure is assessed through the use of the Soil and Water Assessment Tool (SWAT).

An example application of LPRDSS to assess the water quality impacts of manure application in the Hundred and Two Mile River watershed demonstrates its capability and functionality. Overall, the results from the biophysical modeling shows that the model to be an effective tool in the prediction of nutrient runoff to the watershed outlet.

The decision support system developed in this research can contribute to the development of sustainable livestock production systems. Many counties in the Midwest are pursuing expansions in livestock production as an economic development strategy. With this expansion of the livestock industry comes increased concerns for environmental pollution. LPRDSS should provide the analytical tools needed by decision-makers and the livestock industry in planning sustainable livestock production practices.

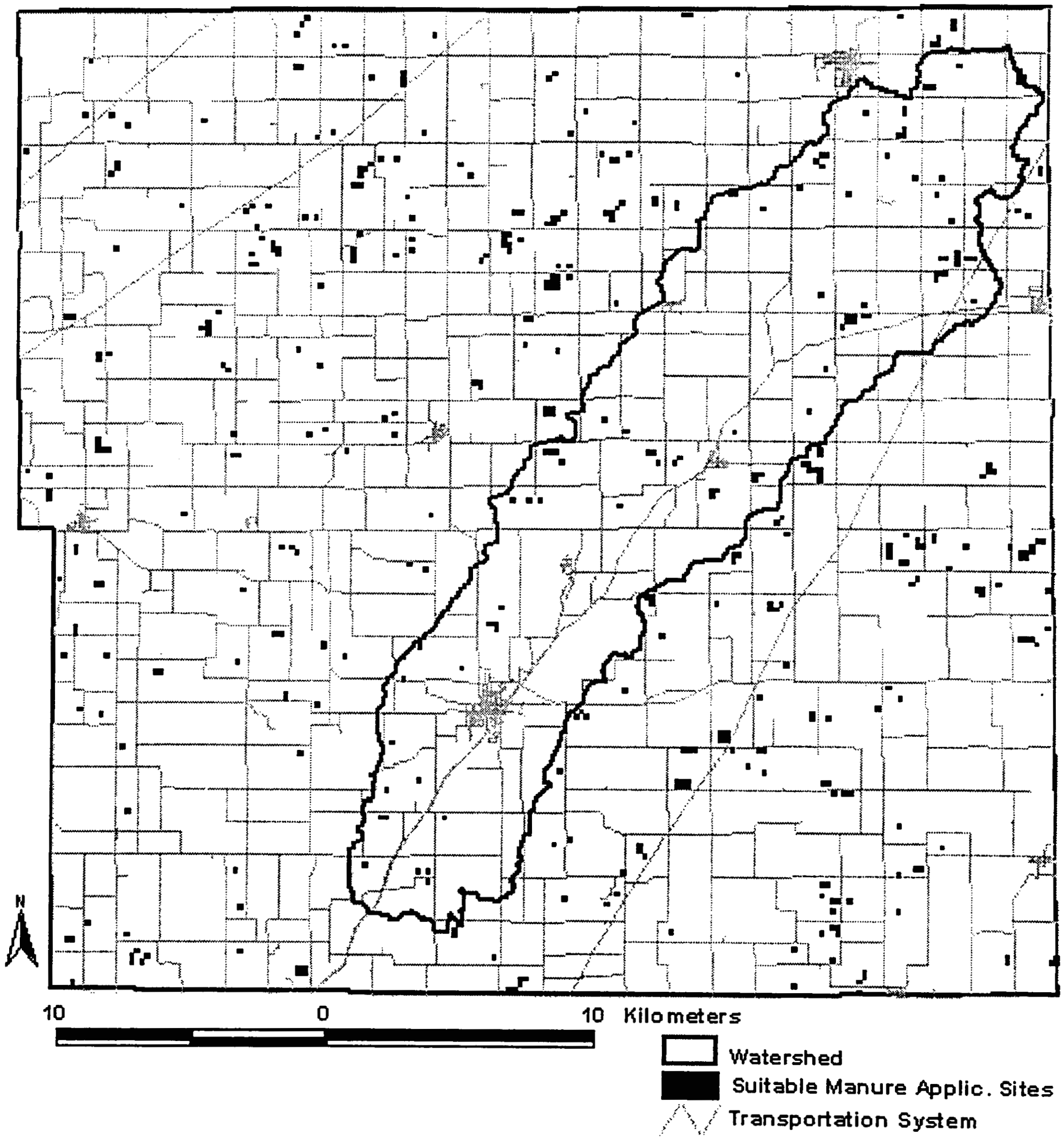

Figure 12. Location of suitable areas for manure application in Taylor County, Iowa using criteria from scenarios 1 and 2 after corn and soybeans are rotated.

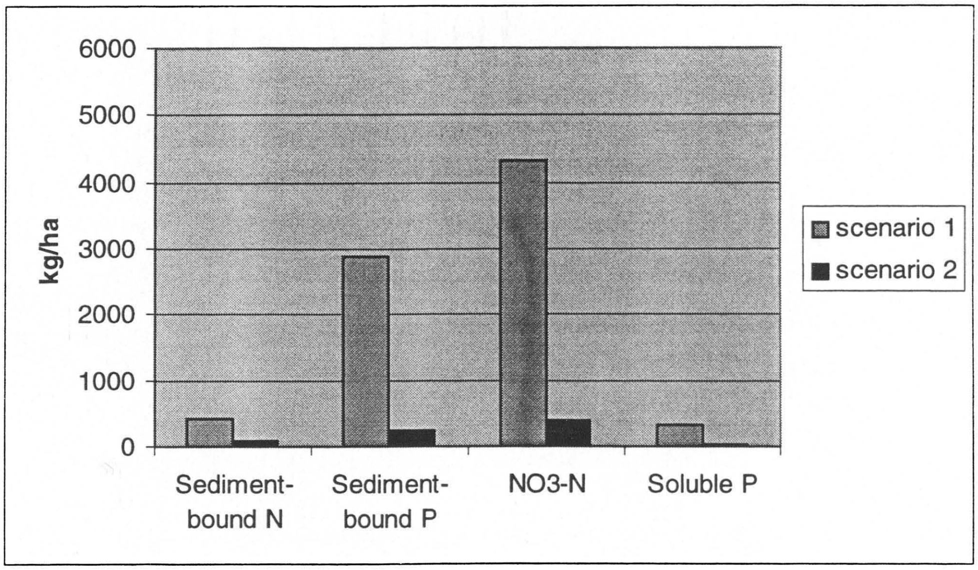

Figure 13. SWAT results from scenario 1 and 2 in the Hundred and Two Mile River watershed in Taylor County, Iowa after corn and soybeans are rotated.

References

Arentze, T.A., A.W.J. Borgers, and H.J.P. Timmermans. 1996. Design of a View-Based DSS for Location Planning. International Journal of Geographical Information Systems 10:219-236.

Arnold, J.G. J.R. Williams, A.D. Nicks, and N.B. Sammons. 1990. SWRRB: A Basin Scale Simulation Model for Soil and Water Resource Management. College Station, TX: Texas A & M. University

Armstrong, M.P., G. Rushton, R. Hoeney, B.T. Dalziel, P. Loolonis, S. De, and P.J. Densham. 1991. Decision Support System for Regionalization: A Spatial Decision Support System for Regionalizing Service Delivery Systems. Computer, Environment, and Urban Systems 15:37-53.

Arnold, J.G. R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development. Journal of the American Water Resources Association 34:73-89.

Beasley, D.B., L.F. Huggins, and E.J. Monke. 1980. ANSWERS: A Model for Watershed Planning. Transactions of the ASAE 23:938-944.

Beven, K.J. and M.J. Kirkby. 1979. A Physically Based, Variable Contributing Model of Basin Hydrology. Hydrological Sciences 24:43-69.

Cho, S.M., G.D. Jennings, C. Stallings, and H.A. Devine. 1995. GIS-Based Water Quality Model Calibration in the Delaware River Basin. Paper No. 952402. St. Joseph, MI: American Society of Agricultural Engineers.

Densham, P.J. 1991. Spatial Decision Support Systems. pp 403-412. In Geographical Information Systems : Principles. D.J. Maguire, M.F. Goodchild, and D.W. Rhind (Editors). New York, NY:Springer Verlang.

DiLuzio, M., R. Srinivasan, and J.G. Arnold. 1997. An Integrated User Interface for SWAT using ArcView and Avenue. Paper No. 972235. St. Joseph, MI: American Society of Agricultural Engineers.

Environmental Protection Agency. 1997. National Water Quality Inventory: 1996 Report to Congress (EPA 841-R-97-008). Washington, D.C.: Office of Water, U.S. Environmental Protection Agency.

Houlahan, J., W.A. Marcus, and A. Shirmohammadi. 1992. Estimating Maryland Critical Area Act's Impact on Future Non-Point Source Pollution along the Rhode River Estuary. Water Resources Bulletin 28:553-567.

Iowa Soil Survey, 1986. Soil Survey for Taylor County, Iowa. Washington, D.C: U.S. Department of Agriculture.

Jain, D.K., U.S. Tim, and R. Jolly. 1995. Spatial Decision Support System for Planning Sustainable Livestock Production. Computer, Environmental, and Urban Systems 19:57-75.

Liao, H. H. and U. S. Tim. 1997. An Interactive Modeling Environment for Non-point Source Pollution Control. Journal of American Water Resource Association, 33:591-603.

Manguerra, H.B. and B.A. Engel. 1998. Hydrologic Parameterization of a Watershed for Runoff Prediction using SWAT. Journal of American Water Resources Association 34:1149-1162.

Rosenthal, W.D., R. Srinivasan, J.G. Arnold. 1995. Alternative River Management Using a Linked GIS-Hydrology Model. Transactions of the ASAE 38:738-790.

Schaffer, M.J., A.D. Halverson, and F.J. Pierce. 1991. Nitrate Leaching and Economic Analysis Package (NLEAP): Model Description and Application. In: Managing Nitrogen for Groundwater Quality and Farm Profitability. Eds. Follet et al. Madison, Wisconsin: Soil Science Society of America.

Srinivasan, R., T.S. Ramanarayanan, R. Jayakrishnan, H.Wang. 1997. Hydrologic Modeling of Rio Grande/Rio Bravo Basin. Paper No. 972236. St. Joseph, MI: American Society of Agricultural Engineers.

Srinivasan, R. B.A. Engel. 994. A Spatial Decision Support System for Assessing Agricultural Nonpoint Source Pollution. Water Resources Bulletin 30:441-452.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1984. A Modeling Approach to Determine the Relationship Between Erosion and Soil Productivity. Transactions of the ASAE 27:129-144.

Williams, J.R. and H.D. Berndt. 1977. Sediment Yield Prediction Based on Watershed Hydrology. Transactions of the ASAE 20:1100-1104.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1989. AGNPS: A Nonpoint Source Pollution Model for Evaluating Agricultural Watersheds. Journal of Soil and Water Conservation 44:168-173.

CHAPTER 5. GENERAL CONCLUSIONS

Summary

Non-point and more recently point source pollution from livestock operations have become a serious environmental concern. As the size of livestock operations increase so do the concerns regarding environmental contamination, specifically surface and ground water pollution. With larger livestock operations there are greater application rates of manure nutrients to a more concentrated land area, further increasing the potential for water contamination In addition to water pollution, air quality concerns, in the form of odor from livestock operations has received increased attention. Residents located near livestock facilities complain that livestock odors adversely affect the quality of their lives, cause unknown long-term health problems, and reduce real estate property values. Thus, there is a need for analytical tools and decision support systems (DSS) to guide the producer and decision-maker in delineating livestock production sites and practices that are environmentally sound, technically defensible, and socially acceptable.

The overall goal of this research was to develop a DSS to facilitate analysis and management of environmental problems associated with livestock production. To accomplish this objective, a GIS-based DSS was developed that integrates a multi-criteria site selection model, a biophysical model, and an atmospheric dispersion model into a framework that can assist planners and decision-makers in selecting suitable land areas both for siting livestock operations and for manure application, and to analyze the potential water quality and regional atmospheric consequences of production practices.

The use of the GIS-based DSS greatly simplifies the site selection and modeling process by providing the tools to generate, manage, manipulate, and display disparate data. Operated under the ArcView GIS environment, the DSS brings the required modeling functionality to the desktop computer and provides a user-friendly environment for data input and visualization. ArcView GIS was chosen as the development platform for several reasons, including: (1) its user friendly menu-driven interface; (2) it is widely used GIS software that contains both raster and vector based modules for effective database management and manipulation; and (3) its ability to operate on a standard desktop computer with reasonable speed and consistency.

Specifically, the multi-criteria site selection model allows the users to choose optimal land areas for locating production sites and manure application areas that meet different and conflicting environmental and social objectives. It uses a spatial weighting scheme and incorporates fourteen different environmental, social, political, and regulatory variables that may influence siting decisions. The atmospheric dispersion model allows users to predict potential air quality impacts of the siting decisions. It also allows users to test hypothesis and learn how key meteorological parameters affect the spatial distribution of odor from a facility. The biophysical model uses the SWAT (Soil and Water Assessment Tool) to enable users to evaluate the soil and water quality (runoff and leaching losses of nutrients) implications of different livestock production options and manure/fertilizer management practices at a watershed-scale.

In this study, the LPRDSS was used to assess areas in Taylor County, Iowa for siting large-scale swine confinement operations and to evaluate on air quality. A biophysical modeling application to the Hundred and Two Mile River watershed provided quantitative information on the water quality implications of livestock production practices and an environment to assess potential impacts of alternative management options.

Future Research

Many areas of this research can be improved on. For example, future research could be conducted to identify options for making the DSS usable to a wider range of users (e.g. policy-makers, producers, producer groups) by developing an enhanced Web-based interface. The rapid advancements in GIS and Internet technologies have allowed some basic maps to be published on the Internet, significantly providing users with the tools and environment to analyze data and maps. Through the use of fifth generation programming languages (e.g. Java), an interactive graphical interface can be developed on the Internet using software packages such as the Internet Map Explorer developed by Environmental Systems Research Institute.

A more thorough study could also be conducted to improve the predictions from the atmosphere dispersion model by accounting for real-time meteorological data and enabling the output results to be displayed in dynamic rather than static format. Static representation of environmental data tends to bias results and may often be misleading. Residents may point to an area and say "Look at how bad the odor pollution is near my home", when in fact the area may be affected by odor emission for a relatively short period of time or when atmospheric conditions are atypical for the area.

Finally, the biophysical component of LPRDSS could also be improved by integrating a field-based water quality model with the watershed-level SWAT model to allow for more localized analysis of the impacts of manure application. At present, the site selection module determines fields suitable for the land application of animal waste, but the SWAT does not permit development and evaluation of site-specific nutrient management plans.

APPENDIX. AVENUE SCRIPTS

'SCRIPT: ABSOLUTE SUITABILITY
'PROGRAMMER: I.M. CRAWFORD
'DATE: 6.98

```
av.GetProject.FindDialog("Facility Absolute").Close
thisProject = av.GetProject
theView = av GetActiveDoc
theViewWin = theView.GetWin
if(theViewWin.IsOpen Not) then
theViewWin.Open
end

hydAFW = self GetDialog.FindByName("aTextLine17").GetText.AsNumber
permAFW = self.GetDialog.FindByName("aTextLine16").GetText.AsNumber
roadAFW = self GetDialog FindByName("aTextLine18") GetText.AsNumber
road2AFW = self.GetDialog FindByName("aTextLine19") GetText AsNumber
slopeAFW = self.GetDialog.FindByName("aTextLine21").GetText.AsNumber
lakeAFW = self.GetDialog FindByName("aTextLine22").GetText.AsNumber
icrpAFW = self.GetDialog.FindByName("aTextLine20").GetText.AsNumber
aspectAFW = self.GetDialog FindByName("aTextLine11").GetText.AsNumber
aspect2AFW = self.GetDialog FindByName("aTextLine12").GetText AsNumber
specAFW = self.GetDialog.FindByName("aTextLine23").GetText.AsNumber
wellAFW = self.GetDialog.FindByName("aTextLine24").GetText.AsNumber
wetlAFW = self GetDialog FindByName("aTextLine24") GetText.AsNumber
drainAFW = self.GetDialog FindByName("aTextLine31").GetText.AsNumber
floodAFW = self.GetDialog.FindByName("aTextLine33").GetText.AsNumber
residAFW = self.GetDialog FindByName("aTextLine10") GetText AsNumber
_HydroAV = self.GetDialog.FindByName("aTextLine43").GetText
_DrainAV = self.GetDialog FindByName("aTextLine1").GetText
_RoadAV = self.GetDialog.FindByName("aTextLine46").GetText
SlopeAP = self GetDialog FindByName("aTextLine48").GetText AsString
_LakeAV = self.GetDialog.FindByName("aTextLine49").GetText
_IcrpAV = self GetDialog.FindByName("aTextLine47").GetText
AspectAP = self GetDialog.FindByName("aTextLine45").GetText
_SpecAV = self.GetDialog.FindByName("aTextLine50") GetText
_WellAV = self.GetDialog.FindByName("aTextLine51").GetText
_WetlAV = self.GetDialog.FindByName("aTextLine52").GetText
_PermAV = self.GetDialog.FindByName("aTextLine44") GetText
_FloodAV = self.GetDialog.FindByName("aTextLine3").GetText
_landAV = self.GetDialog FindByName("aTextLine2") GetText
_ResidAV = self GetDialog FindByName("aTextLine8").GetText

'soil drainage
temp1 = _DrainAV+" poly"
aSrcName = SrcName.Make(temp1)
if (aSrcName = NIL) then
 MsgBox.Error("Invalid Soil Theme", "ERROR")
 return NIL
 end
theTheme = Theme.Make(aSrcName)
theTheme.SetActive(True)

d = theTheme
ddef = av.GetProject.MakeFileName ("drain", "")
anDTab = d GetFTab
dfl = {}
for each df in anDTab.GetFields
  if (df.IsVisible and (df.IsTypeNumber or df.IsTypeString)) then
    dfl Add(df)
  end
end
if (dfl.Count = 0) then
  return NIL
end
theDocName = theView.GetClass.GetClassName
adFN = SourceManager.PutDataSet(GRID,"Convert " + d.getName,ddef,TRUE)
if (adFN = NIL) then
```

```
  return NIL
end
ae = theView.GetExtension(AnalysisEnvironment)
box = Rect Make(0@0,1@1)
cellSize = 1
if ((ae.GetExtent(box) <> #ANALYSISENV_VALUE) or (ae.GetCellSize(cellSize) <>
#ANALYSISENV_VALUE)) then
  ce = AnalysisPropertiesDialog.Show(theView,TRUE,"Conversion Extent:" ++ d GetName)
  if (ce = NIL) then
    return NIL
  end
  ce GetCellSize(cellSize)
  ce.GetExtent(box)
end

aDield = MsgBox.List(dfl,"Pick Soil Drainage Cell Values·","Drainage Conversion Field ·" ++
d.GetName)
if (aDield = NIL) then
  return NIL
end

'soil permeability

temp2 = _PermAV+" poly"
aSrcName = SrcName Make(temp2)
if (aSrcName = NIL) then
 MsgBox.Error("Invalid Soil Theme", "ERROR")
 return NIL
 end
theTheme = Theme.Make(aSrcName)
theTheme.SetActive(True)
P = theTheme
theView= av.GetActiveDoc
    pdef = av.GetProject MakeFileName ("perm", "")
anpFTab = p.GetFTab
pfl = {}
for each pf in anpFTab GetFields
  if (pf IsVisible and (pf IsTypeNumber or pf.IsTypeString)) then
    pfl.Add(pf)
  end
end

if (pfl.Count = 0) then
  return NIL
end

theDocName = theView.GetClass.GetClassName
apFN = SourceManager.PutDataSet(GRID,"Convert " + p.getName,pdef,TRUE)
if (apFN = NIL) then
  return NIL
end

aPield = MsgBox.List(pfl,"Pick Permeability Cell Values.","Soil Perm.Conversion Field :" ++
p.GetName)
if (aPield = NIL) then
  return NIL
end

'flood frequency
temp3 = _FloodAV+" poly"
aSrcName = SrcName.Make(temp3)
if (aSrcName = NIL) then
 MsgBox.Error("Invalid Soil Theme", "ERROR")
 return NIL
 end
theTheme = Theme Make(aSrcName)
theTheme.SetActive(True)
f = theTheme
theView= av.GetActiveDoc
```

```
fdef = av.GetProject MakeFileName ("flood", "")
anfFTab = f.GetFTab
ffl = {}
for each ff in anfFTab GetFields
  if (ff.IsVisible and (ff IsTypeNumber or ff IsTypeString)) then
    ffl.Add(ff)
  end
end
if (ffl.Count = 0) then
  return NIL
end
theDocName = theView.GetClass.GetClassName
afFN = SourceManager.PutDataSet(GRID,"Convert " + f getName,fdef,TRUE)
if (afFN = NIL) then
  return NIL
end
afField = MsgBox List(ffl,"Pick Flood Freq  Cell Values ","Flood Freq.Conversion Field :" ++
f.GetName)
if (afField = NIL) then
  return NIL
end
temp4 = _landAV+" poly"
aSrcName = SrcName Make(temp4)
if (aSrcName = NIL) then
 MsgBox.Error("Invalid Soil Theme", "ERROR")
 return NIL
 end
theTheme = Theme Make(aSrcName)
theTheme.SetActive(True)
l = theTheme
theView= av GetActiveDoc
    ldef = av.GetProject MakeFileName ("landu", "")
anlFTab = l GetFTab
lfl = {}
for each l in anlFTab.GetFields
  if (l.IsVisible and (l.IsTypeNumber or l.IsTypeString)) then
    lfl.Add(l)
  end
end
if (lfl.Count = 0) then
  return NIL
end
theDocName = theView.GetClass.GetClassName
alFN = SourceManager.PutDataSet(GRID,"Convert " + l.getName,ldef,TRUE)
if (alFN = NIL) then
  return NIL
end
alField = MsgBox.List(lfl,"Pick Landuse Cell Values ","Landuse Conversion Field  " ++
l.GetName)
if (alField = NIL) then
  return NIL
end

' drainage
aPrj = theView.GetProjection
aGrid = Grid.MakeFromFTab(anDTab,aPrj,aDield,{cellSize, box})
if (aGrid.HasError) then
  MsgBox.Error(d.GetName ++ "could not be converted to a grid","Conversion Error")
  return NIL
end
status = Grid.GetVerify
Grid.SetVerify(#GRID_VERIFY_OFF)
if (aGrid SaveDataSet(adFN).Not) then
  Grid.SetVerify(status)
  return NIL
end
aGrid1 = (aGrid > drainAFW).con(10 AsGrid,0.AsGrid)
Grid.SetVerify(status)
gthm = GTheme.Make(aGrid1)
```

```
gthm.SetName("Soil Drainage")
_drainAG = gthm
theView.AddTheme(gthm)
theTheme.SetActive(false)
gthm.SetActive(false)

'soil permeability
ce.GetCellSize(cellSize)
  ce GetExtent(box)
aPrj = theView GetProjection
aGrid = Grid.MakeFromFTab(anpFTab,aPrj,aPield,{cellSize, box})
if (aGrid.HasError) then
  MsgBox Error(p.GetName ++ "could not be converted to a grid","Conversion Error")
  return NIL
end
status = Grid.GetVerify
Grid SetVerify(#GRID_VERIFY_OFF)
if (aGrid.SaveDataSet(apFN) Not) then
  Grid.SetVerify(status)
  return NIL
end
aGrid1 = (aGrid > permAFW) con(10 AsGrid,0.AsGrid)
Grid.SetVerify(status)
gthm = GTheme.Make(aGrid1)
gthm.SetName("Soil Permeability")
_permAG = gthm
theView.AddTheme(gthm)
theTheme.SetActive(false)
gthm.SetActive(false)

'flood frequency
ce.GetCellSize(cellSize)
  ce.GetExtent(box)
aPrj = theView.GetProjection
aGrid = Grid.MakeFromFTab(anfFTab,aPrj,afField,{cellSize, box})
if (aGrid.HasError) then
  MsgBox.Error(f.GetName ++ "could not be converted to a grid","Conversion Error")
  return NIL
end
status = Grid.GetVerify
Grid.SetVerify(#GRID_VERIFY_OFF)
if (aGrid.SaveDataSet(afFN).Not) then
  Grid.SetVerify(status)
  return NIL
end
aGrid1 = (aGrid < floodAFW).con(10.AsGrid,0 AsGrid)
Grid.SetVerify(status)
gthm = GTheme.Make(aGrid1)
gthm.SetName("Flood Frequency")
_floodAG = gthm
theView.AddTheme(gthm)
theTheme.SetActive(false)
gthm.SetActive(false)

'landuse
ce.GetCellSize(cellSize)
  ce.GetExtent(box)
aPrj = theView.GetProjection
aGrid = Grid.MakeFromFTab(anlFTab,aPrj,alField,{cellSize, box})
if (aGrid.HasError) then
  MsgBox.Error(l.GetName ++ "could not be converted to a grid","Conversion Error")
  return NIL
end
status = Grid.GetVerify
Grid.SetVerify(#GRID_VERIFY_OFF)
if (aGrid.SaveDataSet(alFN).Not) then
  Grid.SetVerify(status)
  return NIL
end
```

```
aGrid1 =(( aGrid <= 17).Con(0.AsGrid,( aGrid >= 41) Con(0 AsGrid,10 AsGrid)))
Grid SetVerify(status)
gthm = GTheme.Make(aGrid1)
gthm.SetName("Landuse")
_landAG = gthm
theView AddTheme(gthm)
theTheme.SetActive(false)
gthm.SetActive(false)

'hydrology
temp = _HydroAV+" arc"
aSrcName = SrcName.Make(temp)
if (SrcName.Make(temp)  <> Nil) then
theTheme = Theme Make(aSrcName)
theTheme.SetActive(True)
t = theTheme
if (t.Is(FTHEME)) then
ce.Activate
aPrj = theView.GetProjection
  g = Grid.MakeFromFTab(t.GetFTab, aPrj, NIL, NIL)
if (g.HasError) then
    theView.SetExtension(ae)
    ae.Activate
    return NIL
  end
r = g.EucDistance(NIL, NIL, NIL)
theView.SetExtension(ae)
  ae.Activate
else
aVTab = _HydroAV.GetGrid.GetVTab
  if (aVTab = NIL) then
    g = t.GetGrid
  else
    if (aVTab.GetNumSelRecords > 0) then
      g = t.GetGrid.ExtractSelection
    else
      g = t.GetGrid
    end
  end
if (g.HasError) then return NIL end
r = g.EucDistance(NIL, NIL, NIL)
end
distFN = av.GetProject GetWorkDir.MakeTmp("dist","")
r Rename(distFN)
if (r HasError) then return NIL end
r1 = (r > hydAFW) Con(10.AsGrid,0 AsGrid)
distTheme = GTheme.Make(r1)
distTheme.SetName ("Distance to Streams")
theView.AddTheme(distTheme)
_HydroAG = distTheme
theTheme.SetActive(false)
distTheme.SetActive(false)
end

'Roads
temp = _RoadAV+" arc"
aSrcName = SrcName.Make(temp)
if (SrcName.Make(temp)  <> Nil) then
theTheme = Theme.Make(aSrcName)
theTheme.SetActive(True)
t = theTheme
if (t.Is(FTHEME)) then
ce.Activate
aPrj = theView GetProjection
  g = Grid.MakeFromFTab(t GetFTab, aPrj, NIL, NIL)
if (g.HasError) then
    theView.SetExtension(ae)
    ae.Activate
    return NIL
```

```
   end
 r = g EucDistance(NIL, NIL, NIL)
 theView SetExtension(ae)
   ae.Activate
 else
 aVTab = _RoadAV GetGrid.GetVTab
   if (aVTab = NIL) then
     g = t.GetGrid
   else
     if (aVTab.GetNumSelRecords > 0) then
       g = t.GetGrid.ExtractSelection
     else
       g = t.GetGrid
     end
   end
 if (g HasError) then return NIL end
 r = g EucDistance(NIL, NIL, NIL)
 end
 distFN = av.GetProject.GetWorkDir MakeTmp("dist","")
 r.Rename(distFN)
 if (r.HasError) then return NIL end
 r1 =((r > roadAFW) and (r < road2AFW)).Con(10.AsGrid,0 AsGrid)
 distTheme = GTheme.Make(r1)
 distTheme.SetName("Distance to " + t.GetName)
 _RoadAG = distTheme
 theView.AddTheme(distTheme)
 theTheme.SetActive(false)
 distTheme.SetActive(false)
 end

 ' Spatial.Slope
 theTheme.SetActive(True)
 t = theTheme
 if (t.GetClass.GetClassName = "GTheme") then
   g = t.GetGrid
   r = g.Slope(NIL,FALSE)
 elseif (t.GetClass.GetClassName = "STheme") then
   theTin = t.GetSurface
   box = Rect.Make(0@0,1@1)
   cellSize = 1
   ce = AnalysisPropertiesDialog.Show(theView,TRUE,"Output Grid Specification")
   if (ce = NIL) then
     return NIL
   end
   ce.GetExtent(box)
   ce.GetCellSize(cellSize)
   r = theTin.SlopeAsGrid(cellSize,box,FALSE)
 else
   return NIL
 end
 aFN = av GetProject.GetWorkDir.MakeTmp("slope","")
 r.Rename(aFN)
 if (r.HasError) then
   return NIL
 end
 r1 =(r < slopeAFW).Con(10.AsGrid,0.AsGrid)
 gthm = GTheme.Make(r1)
 theView.AddTheme(gthm)
 gthm.SetName("Land Slope")
 _SlopeAG = gthm
 t.SetActive(false)
 gthm.SetActive(false)

 'Aspect
 theTheme = GTheme.Make(_AspectAV)
 theTheme.SetActive(True)
 t = theTheme
 if (t.GetClass.GetClassName = "GTheme") then
   g = t.GetGrid
```

```
  r = g.Aspect
 elseif (t.GetClass.GetClassName = "STheme") then
  theTin = t.GetSurface
  box = Rect.Make(0@0,1@1)
  cellSize = 1
  ce = AnalysisPropertiesDialog.Show(theView,TRUE,"Output Grid Specification")
  if (ce = NIL) then
    return NIL
  end
  ce.GetExtent(box)
  ce.GetCellSize(cellSize)
  r = theTin.AspectAsGrid(cellSize,box)
 else
  return NIL
 end
 aspectFN = av.GetProject.GetWorkDir.MakeTmp("aspct", "")
 r.Rename(aspectFN)

 if (r.HasError) then
  return NIL
 end
 r1 =((r > aspectAFW) and (r < aspect2AFW)) Con(10.AsGrid,0 AsGrid)
 gthm = GTheme.Make(r1)
 gthm.SetName("Aspect")
 _AspectAG = gthm
 theView.AddTheme(gthm)
 t SetActive(false)
 gthm.SetActive(false)

 'towns
 temp = _IcrpAV+" poly"
 aSrcName = SrcName Make(temp)
 if (SrcName.Make(temp)  <> Nil) then
 theTheme = Theme.Make(aSrcName)
 theTheme.SetActive(True)
 t = theTheme
 if (t.Is(FTHEME)) then
 ce.Activate
 aPrj = theView.GetProjection
   g = Grid.MakeFromFTab(t.GetFTab, aPrj, NIL, NIL)
 if (g.HasError) then
     theView.SetExtension(ae)
     ae.Activate
     return NIL
   end
 r = g.EucDistance(NIL, NIL, NIL)
 theView.SetExtension(ae)
   ae Activate
 else
 aVTab = _IcrpAV.GetGrid.GetVTab
   if (aVTab = NIL) then
     g = t.GetGrid
   else
     if (aVTab.GetNumSelRecords > 0) then
       g = t.GetGrid.ExtractSelection
     else
       g = t.GetGrid
     end
   end
 if (g.HasError) then return NIL end
 r = g.EucDistance(NIL, NIL, NIL)
 end
 distFN = av.GetProject.GetWorkDir.MakeTmp("dist","")
 r.Rename(distFN)
 if (r.HasError) then return NIL end
 r1 =(r < icrpAFW).Con(0 AsGrid,10.AsGrid)
 distTheme = GTheme.Make(r1)
 distTheme.SetName ("Distance to Towns")
 _IncrpAG = distTheme
```

```
theView.AddTheme(distTheme)
theTheme.SetActive(false)
distTheme.SetActive(false)

end

'lakes
temp = _LakeAV+" poly"
aSrcName = SrcName.Make(temp)
if (SrcName.Make(temp)  <> Nil) then
theTheme = Theme.Make(aSrcName)
theTheme.SetActive(True)
t = theTheme
if (t.Is(FTHEME)) then
ce.Activate
aPrj = theView.GetProjection
  g = Grid.MakeFromFTab(t.GetFTab, aPrj, NIL, NIL)
if (g.HasError) then
    theView.SetExtension(ae)
    ae.Activate
    return NIL
  end
r = g.EucDistance(NIL, NIL, NIL)
theView.SetExtension(ae)
  ae.Activate
else
aVTab = _LakeAV.GetGrid GetVTab
  if (aVTab = NIL) then
    g = t.GetGrid
  else
    if (aVTab.GetNumSelRecords > 0) then
      g = t.GetGrid.ExtractSelection
    else
      g = t.GetGrid
    end
  end
if (g.HasError) then return NIL end
r = g.EucDistance(NIL, NIL, NIL)
end
distFN = av.GetProject GetWorkDir MakeTmp("dist","")
r.Rename(distFN)
if (r.HasError) then return NIL end
r1 =(r < lakeAFW).Con(0.AsGrid,10.AsGrid)
distTheme = GTheme.Make(r1)
distTheme.SetName("Distance to Lakes")
_LakeAG = distTheme
theView.AddTheme(distTheme)
theTheme.SetActive(false)
distTheme.SetActive(false)
Grid2 = _LakeAG.GetGrid
end

'Special Locations
temp = _SpecAV+" point"
aSrcName = SrcName.Make(temp)
if (SrcName.Make(temp)  <> Nil) then
theTheme = Theme.Make(aSrcName)
theTheme.SetActive(True)

t = theTheme
if (t Is(FTHEME)) then
ce.Activate
aPrj = theView.GetProjection
  g = Grid.MakeFromFTab(t.GetFTab, aPrj, NIL, NIL)
if (g.HasError) then
    theView.SetExtension(ae)
    ae.Activate
    return NIL
  end
```

```
r = g.EucDistance(NIL, NIL, NIL)
theView.SetExtension(ae)
  ae.Activate
else
aVTab = _SpecAV.GetGrid.GetVTab
  if (aVTab = NIL) then
    g = t.GetGrid
  else
    if (aVTab.GetNumSelRecords > 0) then
      g = t GetGrid.ExtractSelection
    else
      g = t.GetGrid
    end
  end
if (g.HasError) then return NIL end
r = g EucDistance(NIL, NIL, NIL)
end
distFN = av.GetProject.GetWorkDir.MakeTmp("dist","")
r Rename(distFN)
if (r.HasError) then return NIL end
r1 =(r < specAFW).Con(0 AsGrid,10.AsGrid)
distTheme = GTheme Make(r1)
distTheme.SetName("Distance to Special Areas")
_SpecAG = distTheme
theView.AddTheme(distTheme)
theTheme.SetActive(false)
distTheme.SetActive(false)
Grid4 = _SpecAG.GetGrid
end

'Residents/Houses
temp = _ResidAV+" point"
aSrcName = SrcName.Make(temp)
if (SrcName.Make(temp)  <> Nil) then
theTheme = Theme.Make(aSrcName)
theTheme.SetActive(True)
t = theTheme
if (t.Is(FTHEME)) then
ce.Activate
aPrj = theView.GetProjection
  g = Grid.MakeFromFTab(t GetFTab, aPrj, NIL, NIL)
if (g.HasError) then
    theView.SetExtension(ae)
    ae.Activate
    return NIL
  end
r = g.EucDistance(NIL, NIL, NIL)
theView.SetExtension(ae)
  ae.Activate
else
aVTab = _ResidAV.GetGrid.GetVTab
  if (aVTab = NIL) then
    g = t.GetGrid
  else
    if (aVTab GetNumSelRecords > 0) then
      g = t.GetGrid.ExtractSelection
    else
      g = t.GetGrid
    end
  end
if (g.HasError) then return NIL end
r = g.EucDistance(NIL, NIL, NIL)
end
distFN = av GetProject.GetWorkDir.MakeTmp("dist","")
r.Rename(distFN)
if (r.HasError) then return NIL end
r1 =(r < residAFW) Con(0.AsGrid,10.AsGrid)
distTheme = GTheme.Make(r1)
distTheme.SetName("Distance to Residence")
```

```
_ResidAG = distTheme
theView AddTheme(distTheme)
theTheme.SetActive(false)
distTheme.SetActive(false)
end

'Wells
temp = _WellAV+" point"
aSrcName = SrcName.Make(temp)
if (SrcName.Make(temp)  <> Nil) then
theTheme = Theme.Make(aSrcName)
theTheme.SetActive(True)
t = theTheme
if (t.Is(FTHEME)) then
ce Activate
aPrj = theView.GetProjection
  g = Grid.MakeFromFTab(t GetFTab, aPrj, NIL, NIL)
if (g.HasError) then
    theView SetExtension(ae)
    ae Activate
    return NIL
  end
r = g.EucDistance(NIL, NIL, NIL)
theView.SetExtension(ae)
  ae.Activate
else
aVTab = _WellAV.GetGrid GetVTab
  if (aVTab = NIL) then
    g = t.GetGrid
  else
    if (aVTab.GetNumSelRecords > 0) then
      g = t.GetGrid.ExtractSelection
    else
      g = t GetGrid
    end
  end
if (g.HasError) then return NIL end
r = g.EucDistance(NIL, NIL, NIL)
end
distFN = av.GetProject.GetWorkDir.MakeTmp("dist","")
r.Rename(distFN)
if (r.HasError) then return NIL end
r1 =(r < wellAFW).Con(0.AsGrid,10 AsGrid)
distTheme = GTheme.Make(r1)
distTheme.SetName("Distance to Wells")
_WellAG = distTheme
theView AddTheme(distTheme)
theTheme.SetActive(false)
distTheme.SetActive(false)
Grid5 = _WellAG.GetGrid
end

'Wetlands
temp = _WetlAV+" poly"
aSrcName = SrcName.Make(temp)
if (SrcName.Make(temp)  <> Nil) then
theTheme = Theme.Make(aSrcName)
theTheme.SetActive(True)
t = theTheme
if (t.Is(FTHEME)) then
ce.Activate
aPrj = theView.GetProjection
  g = Grid.MakeFromFTab(t.GetFTab, aPrj, NIL, NIL)
if (g.HasError) then
    theView.SetExtension(ae)
    ae.Activate
    return NIL
  end
r = g.EucDistance(NIL, NIL, NIL)
```

```
theView SetExtension(ae)
  ae.Activate
else
aVTab = _WetlAV.GetGrid GetVTab
  if (aVTab = NIL) then
    g = t.GetGrid
  else
    if (aVTab.GetNumSelRecords > 0) then
      g = t.GetGrid.ExtractSelection
    else
      g = t.GetGrid
    end
  end
if (g.HasError) then return NIL end
r = g.EucDistance(NIL, NIL, NIL)
end
distFN = av GetProject.GetWorkDir MakeTmp("dist","")
r Rename(distFN)
if (r.HasError) then return NIL end
r1 =(r < wetlAFW).Con(0 AsGrid,10 AsGrid)
distTheme = GTheme.Make(r1)
distTheme.SetName("Distance to Wetlands")
_WetAG = distTheme
theView.AddTheme(distTheme)
theTheme.SetActive(false)
distTheme.SetActive(false)
Grid6 = _WetAG.GetGrid
end

if (_HydroAG <> Nil) then
Grid1 = _HydroAG.GetGrid
else
Grida = 0 AsGrid
Grid1a = GTheme.Make(Grida)
Grid1 = Grid1a.GetGrid
end
if (_LakeAG <> Nil) then
Grid2 = _LakeAG.GetGrid
else
Gridb = 0.AsGrid
Grid2b = GTheme.Make(Gridb)
Grid2 = Grid2b.GetGrid
end
if (_RoadAG <> Nil) then
Grid3 = _RoadAG.GetGrid
else
Gridc = 0.AsGrid
Grid3c = GTheme.Make(Gridc)
Grid3 = Grid3c.GetGrid
end
if (_SpecAG <> Nil) then
Grid4 = _SpecAG.GetGrid
else
Gridd = 0.AsGrid
Grid4d = GTheme.Make(Gridd)
Grid4 = Grid4d.GetGrid
end
if (_WellAG <> Nil) then
Grid5 = _WellAG.GetGrid
else
Gride = 0.AsGrid
Grid5e = GTheme Make(Gride)
Grid5 = Grid5e.GetGrid
end
if (_WetAG <> Nil) then
Grid6 = _WetAG.GetGrid
else
Gridf = 0 AsGrid
Grid6f = GTheme.Make(Gridf)
```

```
Grid6 = Grid6f.GetGrid
end
if (_IncrpAG <> Nil) then
Grid7 = _IncrpAG.GetGrid
else
Gridg = 0.AsGrid
Grid7g = GTheme.Make(Gridg)
Grid7 = Grid7g GetGrid
end
if (_drainAG <> Nil) then
Grid8 = _drainAG.GetGrid
else
Gridh = 0 AsGrid
Grid8h = GTheme Make(Gridh)
Grid8 = Grid8h.GetGrid
end
if (_AspectAG <> Nil) then
Grid10 = _AspectAG.GetGrid
else
Gridj = 0.AsGrid
Grid10j = GTheme.Make(Gridj)
Grid10 = Grid10j.GetGrid
end
if (_SlopeAG <> Nil) then
Grid9 = _SlopeAG GetGrid
else
Gridi = 0.AsGrid
Grid9i = GTheme.Make(Gridi)
Grid9 = Grid9i.GetGrid
end
if (_floodAG <> Nil) then
Grid11 = _floodAG.GetGrid
else
Gridk = 0.AsGrid
Grid11k = GTheme.Make(Gridk)
Grid11 = Grid11k.GetGrid
end
if (_permAG <> Nil) then
Grid12 = _permAG.GetGrid
else
Gridl = 0.AsGrid
Grid12l = GTheme Make(Gridl)
Grid12 = Grid12l.GetGrid
end
if (_landAG <> Nil) then
Grid13 = _landAG.GetGrid
else
Gridm = 0.AsGrid
Grid13m = GTheme.Make(Gridm)
Grid13 = Grid13m.GetGrid
end
if (_ResidAG <> Nil) then
Grid14 = _ResidAG.GetGrid
else
Gridn = 0.AsGrid
Grid14n = GTheme.Make(Gridn)
Grid14 = Grid14n.GetGrid
end

SuitGrid =
(Grid1*Grid2*Grid3*Grid4*Grid5*Grid6*Grid7*Grid8*Grid9*Grid10*Grid11*Grid12*Grid13*Grid14)
r = (SuitGrid = 0).Con(0.AsGrid,1.AsGrid)
t = GTheme.Make(r)
t.SetActive(true)
theGrid = t.GetGrid
aFileName = "temp.shp".AsFileName
aPrj = theView.GetProjection
theResult = theGrid.AsPolygonFTab(aFileName,TRUE,aPrj)
fthm = FTheme.Make(theResult)
```

```
anFTab = fthm.GetFTab
anFTab SetEditable(true)
f1 = Field Make("acres",#FIELD_DECIMAL,10,0)
anFTab AddFields({f1})
acresField = anFTab FindField("acres")
calcAcres = "([shape].ReturnArea*0 0002471054)"
anFTab.Calculate(calcAcres,acresField)
anFTab SetEditable(false)
theBitMap = anFTab.GetSelection
expr = "(([Acres] > _Aacre ) and ([Acres] < 2000))"
anFTab.Query(expr,theBitMap,#VTAB_SELTYPE_OR)
anFTab.UpdateSelection
theView = av.GetActiveDoc
def = av.GetProject.MakeFileName ("ASuit", "")
t = fthm
anFTab = t.GetFTab
theDocName = theView.GetClass.GetClassName
aFN = SourceManager.PutDataSet(GRID,"Convert " + t.getName,def,TRUE)
if (aFN = NIL) then
  return NIL
end
ae = theView.GetExtension(AnalysisEnvironment)
box = Rect.Make(0@0,1@1)
cellSize = 1
if ((ae.GetExtent(box) <> #ANALYSISENV_VALUE) or (ae.GetCellSize(cellSize) <>
#ANALYSISENV_VALUE)) then
  ce = AnalysisPropertiesDialog.Show(theView,TRUE,"Conversion Extent " ++ t.GetName)
  if (ce = NIL) then
    return NIL
  end
  ce.GetCellSize(cellSize)
  ce.GetExtent(box)
end
aField = anFTab.FindField("Gridcode")
aPrj = theView.GetProjection
aGrid = Grid.MakeFromFTab(anFTab,aPrj,aField,{cellSize, box})
if (aGrid.HasError) then
  MsgBox.Error(t.GetName ++ "could not be converted to a grid","Conversion Error")
  return NIL
end
status = Grid.GetVerify
Grid.SetVerify(#GRID_VERIFY_OFF)
if (aGrid.SaveDataSet(aFN).Not) then
  Grid.SetVerify(status)
  return NIL
end
Grid SetVerify(status)
gthm = GTheme.Make(aGrid)
gthm.SetName("Facility Absol Suit")
_FacGrd = gthm
theView.AddTheme(_FacGrd)
gthm SetActive(false)
```

'SCRIPT: FACILITY ABSOLUTE SIZE
'PROGRAMMER: I.M. CRAWFORD
'DATE: 6.98

```
theComboBox = self.GetDialog.FindByName("aComboBox12")
_theChoice = theComboBox GetCurrentRow
if (_theChoice = 0) then
_Racre = 9.88
_ManProd = 21279 3
end
if (_theChoice = 1) then
_Racre = 2.96
_ManProd = 5319.8
end
```

```
if (_theChoice = 2) then
_Racrce = 1 98
_ManProd = 2080 2
end
if (_theChoice = 3) then
_Racre = 4.94
_ManProd = 4631.3
end
if (_theChoice = 4) then
_Racre = 2.97
_ManProd = 2030 3
end
if (_theChoice = 5) then
_Racre = 2.47
_ManProd = 812.9
end
if (_theChoice = 6) then
_Racre = 3 95
_ManProd = 967.1
end
if (_theChoice = 7) then
_Racre = 2.97
_ManProd = 387.4
end
if (_theChoice = 8) then
_Racre = 1.98
_ManProd = 193.2
end
self.GetDialog.Close
aDialog = av.GetProject.FindDialog("Facility Absolute")
aDialog.Open
```

'SCRIPT: 3D VISUALIZATION OF ODOR PLUME
'PROGRAMMER: I.M. CRAWFORD
'DATE: 1.99

```
theView = av.GetActiveDoc
  thisProject = av GetProject
 theView = thisProject.FindDoc("3D Odor Model")
  theViewWin = theView.GetWin
  if (theViewWin.IsOpen.Not) then
    theViewWin.Open
end
def = av GetProject.MakeFileName ("nwtin", "")
    ' obtain tolerance for conversion
    theStats = _dem.GetStatistics
    suggestTol = (theStats.Get(1) - theStats.Get(0)) * 0 05
    status = TRUE
    while (status)
      theTol = MsgBox.Input("Enter z-value tolerance (in z-value units):","Convert Grid to
TIN :" ++ _dem GetName,suggestTol.AsString)
      if (theTol = NIL) then
        break
      end
      if (theTol.IsNumber and (theTol.AsNumber > 0)) then
        status = FALSE
      else
        status = TRUE
        MsgBox.Error("The conversion tolerance must be a number greater than 0","Convert Grid
to TIN :" ++ _dem.GetName)
      end
    end
theTin = Tin.MakeFromGrid(def,_dem,theTol AsNumber)
    theTin.StopEditing(TRUE)
sthm = STheme.Make(theTin)
    theView.AddTheme(sthm)
theView.GetWin.Activate
```

```
theInFTab = _OdCntr.GetFTab
    if (theInFTab.GetShapeClass.GetClassName <> "MultiPatch") then
       theShape = theInFTab.GetShapeClass.MakeNull
      theChoices = {"Surface","Attribute", "Constant"}
      aZSource = MsgBox.ChoiceAsString(theChoices,"Get Z values from.","Convert" ++
_OdCntr.GetName)
      if (aZSource = NIL) then
end
if (aZSource = "Surface") then
        surfaceList = {}
        for each t2 in theView.GetThemes
          if (t2.Is(GTheme) or t2.Is(STheme)) then
            surfaceList.Add(t2)
          end
        end
        if (surfaceList.Count = 0) then
          aSurfFN = SourceManager.GetDataSet({Grid,Tin},"Select Surface  " ++
_OdCntr GetName)
          if (aSurfFN = NIL) then
end
          aSrcName = Grid MakeSrcName(aSurfFN.AsString)
          if (aSrcName <> NIL) then
            theSurface = Grid.Make(aSrcName)
            surfTheme = GTheme.Make(theSurface)
          else
            aSrcName = SrcName.Make(aSurfFN.AsString)
            theSurface = Tin.Make(aSrcName)
            surfTheme = STheme.Make(theSurface)
          end
          theView.AddTheme(surfTheme)
        else
          surfTheme = MsgBox.ListAsString(surfaceList,"Choose theme to use as
surface:","Select Surface :" ++ _OdCntr GetName)
          if (surfTheme = NIL) then
end
          if (surfTheme.Is(GTheme)) then
            theSurface = surfTheme.GetGrid
          elseif (surfTheme.Is(STheme)) then
            theSurface = surfTheme.GetSurface
          else
end
        end
        if (theSurface.Is(Grid)) then
          if (theInFTab.GetShapeClass.IsSubClassOf(PolyLine)) then
            sampleCancel = FALSE
            distStatus = TRUE
            while (distStatus) ' repeat until valid number entered or cancel
              theReturn = MsgBox Input("Sample distance on grid:","Convert" ++
_OdCntr.GetName,theSurface.GetSampleDistance.AsString)
              if (theReturn = NIL) then ' user pressed cancel
                sampleCancel = TRUE
                distStatus = FALSE
              else
                if (theReturn.IsNumber and (theReturn.AsNumber > 0)) then
                  distStatus = FALSE
                else
                  MsgBox Error("Sample distance must be a number greater than 0","Convert" ++
_OdCntr.GetName)
                end
              end
            end
            if (sampleCancel) then ' user cancelled on sample distance, skip theme
'             continue
            end
            dist = theReturn.AsNumber
          else
            dist = 0
          end
        elseif (theSurface.Is(Tin)) then
```

```
          dist = 0
        else
end
      end

      fl = {}
      for each f in theInFTab GetFields
        if (f.IsVisible and f.IsTypeNumber) then
          fl.Add(f)
        end
      end
outFields = {}
      for each f in theInFTab.GetFields
        if (f.IsVisible and f IsTypeShape Not) then
          outFields.Add(f.Clone)
        end
      end
      if (aZsource = "Attribute") then
        zField = MsgBox.List(fl,"Choose the field that will provide the Z value:","Convert"
++ _OdCntr.GetName)
        if (zField = NIL) then
end
      elseif (aZsource = "Constant") then
        theZConstant = MsgBox.Input("Enter constant to be used as Z value ","Convert" ++
_OdCntr.GetName,"0.0")
        if (theZConstant = NIL) then
end
      end
def = av.GetProject.GetWorkDir.MakeTmp("thmz","shp")
      def = SourceManager.PutDataSet(ftab, "Output Shapefile Name  " ++ _OdCntr.GetName, def,
true)
      if (def = NIL) then
end
if (aZSource = "Surface") then
        thePrj = theView.GetProjection
        theOutFTab = theSurface.InterpolateAsFTab(theInFTab, def, thePrj, dist)
      else
        thePrj = Prj MakeNull
        inClass = theInFTab.GetShapeClass
        if (inClass IsSubclassOf(Point)) then
          outClass = PointZ
        elseif (inClass.IsSubclassOf(Polygon)) then
          outClass = PolygonZ
        elseif (inClass.IsSubclassOf(PolyLine)) then
          outClass = PolyLineZ
        elseif (inClass IsSubclassOf(MultiPoint)) then
          outClass = MultiPointZ
        else
end
        theOutFTab = FTab MakeNew(def, outClass)
        theOutFTab.SetEditable(TRUE)
        theOutFTab.AddFields(outFields)
theBitMap = theInFTab.GetSelection
        if (theBitMap.Count = 0) then
          theBitMap.SetAll
          unsetBitmap = TRUE 'reset flag for end of loop
        else
          unsetBitmap = FALSE
        end
        shapeField = theOutFTab.FindField("Shape")
        done = FALSE
        offset = -1
        while (not done)
          recNum = theBitmap.GetNextSet(offset)
          offset = recNum
          if (recNum <> -1) then
            if (theInFTab.QueryShape(recNum, thePrj, theShape)) then
              if (aZSource = "Attribute") then
                z = theInFTab.ReturnValueNumber(zField, recNum)
```

```
            else
              z = theZConstant.AsNumber
            end
            rec = theOutFTab.AddRecord
            theOutFTab.SetValue(shapeField, rec, theShape@z)
            for each f in outFields
              inField = theInFTab.FindField(f.GetAlias)
              attVal = theInFTab.ReturnValue(inField, recNum)
              theOutFTab.SetValue(f, rec, attVal)
            end
          end
        else
          done = TRUE
        end
      end
      theOutFTab.Flush
      theOutFTab.SetEditable(FALSE)
      if (unsetBitmap) then
        theBitmap ClearAll
      end
    end
          fthm = FTheme.Make(theOutFTab)
    theView.AddTheme(fthm)
  end
theView.GetWin.Activate
```

'SCRIPT: ODOR DISPERSION MODEL
'PROGRAMMER: I.M. CRAWFORD
'DATE: 10.98

```
theView = av GetActiveDoc
theTextLine = self.GetDialog.FindByName("aTextLine16")
WndSpd = theTextLine.GetText AsNumber
self.GetDialog.Close
av.Run("CloseSubDialog.Menu",nil)
AXGrid = _AtmParX.GetGrid
AYGrid = _AtmParY.GetGrid
ExpTempX = (_XGrid.Sqr / (2 AsGrid * AXGrid.Sqr))
ExpGridX = GTheme.Make(ExpTempX)
theGridX = ExpGridX.GetGrid
ExpTempY = (_YGrid.Sqr / (2.AsGrid * AYGrid Sqr))
ExpGridY = GTheme.Make(ExpTempY)
theGridY = ExpGridY GetGrid
expTemp = (-1.AsGrid * (theGridX + theGridY))/100
ExpGrid= GTheme.Make (expTemp)
theGrid = ExpGrid.GetGrid
expTemp2 = theGrid exp
ExpGrid2= GTheme.Make (expTemp2)
theGrid3 = ExpGrid2 GetGrid
EqTemp = (100.AsGrid / (3 14.AsGrid * AXGrid * AYGrid * WndSpd.AsGrid))
FnGrd = GTheme.Make(EqTemp)
FnGrd.SetName ("Q Value")
theGrid2 = FnGrd.GetGrid
EqTemp2 = (theGrid2 * theGrid3 )
_OdorPl = GTheme.Make(EqTemp2)
_OdorPl.SetName ("Odor Plume")
theView.AddTheme(_OdorPl)
t = _OdorPl
needDelete = FALSE
aPrj = theView.GetProjection
if (t.GetClass.GetClassName = "FTheme") then
ae = theView.GetExtension(AnalysisEnvironment)
  box = Rect.Make(0@0,1@1)
  cellSize = 1
  if ((ae.GetExtent(box) <> #ANALYSISENV_VALUE) or (ae.GetCellSize(cellSize) <>
#ANALYSISENV_VALUE)) then
    ce = AnalysisPropertiesDialog.Show(theView,TRUE,"Surface Grid Specification")
```

```
    if (ce = NIL) then
      return NIL
    end
    ce.GetCellSize(cellSize)
    ce.GetExtent(box)
  end
theFTab = t.GetFTab
  theClassName = theFTab GetShapeClass.GetClassName
  if ((theClassName = "PointZ") or
      (theClassName = "MultiPointZ") or
      (theClassName = "PointM") or
      (theClassName = "MultiPointM")) then
    needDelete = TRUE
    theFieldList = theFTab GetFields.Clone
    theShapeField = theFTab FindField("Shape")
    theNewShapefile = av.GetProject.GetWorkDir.MakeTmp("cntmp","shp")
    theNewFTab = FTab.MakeNew(theNewShapefile,Point)
    theFieldList.RemoveObj(theShapeField) 'ignore the shape field
    theFieldCount = theFieldList.Count - 1
    theNewShapeField = theNewFTab.FindField("Shape")
    aShape = theFTab.ReturnValue(theShapeField,0)
    hasZcoord = aShape.HasZ
    hasMcoord = aShape.IsMeasured
    if (hasZcoord) then
      zCoordField = Field Make("ShapeZ",#FIELD_DOUBLE,12,3)
      theNewFTab.AddFields({zCoordField})
    end
    if (hasMcoord) then
      mCoordField = Field Make("ShapeM",#FIELD_DOUBLE,12,3)
      theNewFTab.AddFields({mCoordField})
    end
    theNewFieldList = theFieldList.DeepClone
    theNewFTab.AddFields(theNewFieldList)
    t = FTheme.Make(theNewFTab)
  end
interpList = InterpolationDialog.Show(t, cellSize)
  if (interpList Count < 2) then
    if (needDelete) then
      theNewFTab.SetEditable(FALSE)
      t = NIL
      theFTab DeActivate
      theFTab = NIL
      theNewFTab.DeActivate
      theNewFTab = NIL
      av PurgeObjects
      File.Delete(theNewShapefile)
      theNewShapefile SetExtension("shx")
      File.Delete(theNewShapefile)
      theNewShapefile.SetExtension("dbf")
      File.Delete(theNewShapefile)
    end
    return NIL
  end
  zField = interpList.Get(0)
  anInterp = interpList.Get(1)
if ((theClassName = "PointZ") or
      (theClassName = "MultiPointZ") or
      (theClassName = "PointM") or
      (theClassName = "MultiPointM")) then
    av.ClearMsg
    av.ClearStatus
    av.ShowStopButton
    av.ShowMsg("Exporting Shapes. .")
    theIndex = 0
    theBitMap = theFTab.GetSelection
    if (theBitMap.Count = 0) then
      numFeatures = theFTab.GetNumRecords
      theBitMap.SetAll
      unsetBitmap = TRUE 'reset flag for end of loop
```

```
else
  numFeatures = theFTab GetNumSelRecords
  unsetBitmap = FALSE
end
done = FALSE
offset = -1
while (not done)
  rec = theBitmap.GetNextSet(offset)
  offset = rec
  if (rec <> -1) then
    theShape = theFTab.ReturnValue(theShapeField,rec)
    if ((theClassName = "PointZ") or
        (theClassName = "PointM")) then
      if (zField GetName = "ShapeZ") then
        theZ = theShape.GetZ
        if (theZ.IsNull.Not) then
          theNewRecnum = theNewFTab AddRecord
          theNewFTab.SetValue(zCoordField,theNewRecnum,theZ)
          theShape = theShape.AsPoint
          theNewFTab.SetValue(theNewShapeField,theNewRecnum,theShape)
        end
      elseif (zField GetName = "ShapeM") then
        theM = theShape.GetM
        if (theM.IsNull.Not) then
          theNewRecnum = theNewFTab.AddRecord
          theNewFTab.SetValue(mCoordField,theNewRecnum,theM)
          theShape = theShape.AsPoint
          theNewFTab.SetValue(theNewShapeField,theNewRecnum,theShape)
        end
      else
        theValue = theFTab.ReturnValue(theFTab.FindField(zField GetName),rec)
        if (theValue IsNull.Not) then
          theNewRecnum = theNewFTab.AddRecord
          theNewFTab.SetValue(zField,theNewRecnum,theValue)
          theShape = theShape.AsPoint
          theNewFTab.SetValue(theNewShapeField,theNewRecnum,theShape)
        end
      end
    elseif ((theClassName = "MultiPointZ") or
            (theClassName = "MultiPointM")) then
      for each p in theShape.AsList
        if (zField.GetName = "ShapeZ") then
          theZ = p.GetZ
          if (theZ.IsNull.Not) then
            theNewRecnum = theNewFTab.AddRecord
            theNewFTab.SetValue(zCoordField,theNewRecnum,theZ)
            p = p.AsPoint
            theNewFTab.SetValue(theNewShapeField,theNewRecnum,p)
          end
        elseif (zField GetName = "ShapeM") then
          theM = p.GetM
          if (theM.IsNull.Not) then
            theNewRecnum = theNewFTab AddRecord
            theNewFTab.SetValue(mCoordField,theNewRecnum,theM)
            p = p.AsPoint
            theNewFTab.SetValue(theNewShapeField,theNewRecnum,p)
          end
        else
          theValue = theFTab.ReturnValue(theFTab.FindField(zField.GetName),rec)
          if (theValue.IsNull.Not) then
            theNewRecnum = theNewFTab.AddRecord
            theNewFTab.SetValue(zField,theNewRecnum,theValue)
            p = p.AsPoint
            theNewFTab SetValue(theNewShapeField,theNewRecnum,p)
          end
        end
      end
    end
    theIndex = theIndex + 1
```

```
        progress = (theIndex/numFeatures) * 100
        doMore = av SetStatus(progress)
        if (not doMore) then
          theNewFTab.SetEditable(FALSE)
          if (unsetBitmap) then
            theBitmap.ClearAll
          end
          t = NIL
          theFTab DeActivate
          theFTab = NIL
          theNewFTab.DeActivate
          theNewFTab = NIL
          av.PurgeObjects
          File.Delete(theNewShapefile)
          theNewShapefile SetExtension("dbf")
          File.Delete(theNewShapefile)
          theNewShapefile SetExtension("shx")
          File Delete(theNewShapefile)
          return NIL
        end
      else
        done = TRUE
      end
    end
    theNewFTab.Flush
    if (unsetBitmap) then
      theBitmap.ClearAll
    end
    if (theNewFTab.GetNumRecords = 0) then
      MsgBox.Error(zField.GetName++" is null for all features","Create Contours")
      theNewFTab.SetEditable(FALSE)
      t = NIL
      theFTab.DeActivate
      theFTab = NIL
      theNewFTab.DeActivate
      theNewFTab = NIL
      av.PurgeObjects
      File.Delete(theNewShapefile)
      theNewShapefile.SetExtension("dbf")
      File Delete(theNewShapefile)
      theNewShapefile.SetExtension("shx")
      File.Delete(theNewShapefile)
      return NIL
    end
    theFTab = theNewFTab
  end
r = Grid.MakeByInterpolation(theFTab,aPrj,zField,anInterp,{cellSize, box})
if (needDelete) then
    theNewFTab.SetEditable(FALSE)
    t = NIL
    theFTab.DeActivate
    theFTab = NIL
    theNewFTab.DeActivate
    theNewFTab = NIL
    av.PurgeObjects
    File.Delete(theNewShapefile)
    theNewShapefile SetExtension("shx")
    File.Delete(theNewShapefile)
    theNewShapefile.SetExtension("dbf")
    File.Delete(theNewShapefile)
  end
if (r.HasError) then
    return NIL
  end
  theStatsList = r.GetStatistics
  theRange = theStatsList.Get(1) - theStatsList.Get(0)
elseif (t.GetClass.GetClassName = "STheme") then
  r = t GetSurface
  theRange = r.GetZRange
```

```
elseif (t.GetClass.GetClassName = "GTheme") then
  r = t.GetGrid
  theStatsList = r.GetStatistics
  theRange = theStatsList.Get(1) - theStatsList.Get(0)
else
  return NIL
end
if (theRange = 0) then
  MsgBox.Error("Surface is flat, no contours can be created.","Create Contours")
  return NIL
end
intervals = {
 0. 0.00001,
 0.00001  0.0001,
 0 0001..0 001,
 0.001..0.01,
 0 01..0.1,
 0.1..1,
 1  10,
 10..100,
 100..1000,
 1000..10000,
 10000..100000,
 100000..1000000,
 1000000..(1 / 0)}
theInterval = 1..1
for each i in intervals
  if (i.Find(theRange)) then
    theInterval = i
    break
  end
end
suggestCI = theInterval GetLower / 10
if (suggestCI = 0) then
  suggestCI = 0.0000001
end
status = TRUE
while (status)
  paramsList = MsgBox.MultiInput("Enter parameters:","Odor Plume Parameters",{"Contour
interval:","Base contour:"},{suggestCI.AsString,"0"})
  if (paramsList.Count < 2) then
    return NIL
  end
  theInterval = paramsList.Get(0)
  theBase = paramsList.Get(1)
  if (theInterval.IsNumber and (theInterval.AsNumber > 0)) then
    intervalOK = TRUE
  else
    intervalOK = FALSE
    MsgBox.Error("The contour interval must be a number greater than 0","Create Contours")
  end
  if (theBase.IsNumber) then
    baseOK = TRUE
  else
    baseOK = FALSE
    MsgBox.Error("The base contour must be a number","Create Contours")
  end
  if (intervalOK and baseOK) then
    status = FALSE
  else
    status = TRUE
  end
end
aFN = av.GetProject.GetWorkDir MakeTmp("ctour","shp")
if (r.GetClass.GetClassName = "Grid") then
  contourFTab = r Contour(aFN,theInterval AsNumber,theBase.AsNumber,aPrj)
elseif (r.GetClass.GetClassName = "Tin") then
  contourFTab = r.Contour(aFN,theInterval.AsNumber,theBase.AsNumber,aPrj)
else
```

```
  return NIL
end
if (contourFTab = NIL) then
  return NIL
end
contourFTab.CreateIndex(contourFTab FindField("Shape"))
thm = FTheme.Make(contourFTab)
_OdCntr = thm
thm.SetName("Contours of Odor")
theView.AddTheme(thm)
```

'SCRIPT: ODOR DISPERSION WIND DIRECTION
'PROGRAMMER: I.M. CRAWFORD
'DATE: 11.98

```
theView=av.GetActiveDoc
theGrid = _gthm.GetGrid
XTemp = theGrid*0.AsGrid
if(File.Exists("c:\x.asc".AsFileName)) then
 File.Delete ("c:\x.asc".AsFileName)
end
XTemp.SaveAsAscii("c.\x.asc".AsFileName)
xlf = lineFile.Make("c \x.asc".AsFileName,#FILE_PERM_READ )
xidt = lineFile.Make("c:\xid.asc".AsFileName,#FILE_PERM_WRITE )
data = xlf.ReadElt
xidt.WriteElt(data)
col = data.Extract (1).AsNumber
data = xlf.ReadElt
xidt.WriteElt(data)
row = data.Extract (1).AsNumber
data = xlf.ReadElt
xidt.WriteElt(data)
data = xlf.ReadElt
xidt.WriteElt (data)
data = xlf.ReadElt
xidt WriteElt(data)
data = xlf.ReadElt
xidt WriteElt(data)
count = _fieldCellSize
count1= _fieldCellSize
for each i in 0  (row-1)
data = xlf.ReadElt
buffer = ""
for each j in 0..(col-1)
a=-9999.asstring
if (i >= _curRow) then
  if(j >= _curCol) then
   a = count.AsString
   count = count + _fieldCellSize
   end
end
if (i <= _curRow) then
  if(j >= _curCol) then
   a = count1.AsString
   count1 = count1 + _fieldCellSize
   end
end
buffer = buffer+a+" "
end
xidt.WriteElt(buffer)
count = _fieldCellSize
count1= _fieldCellSize
end
xidt.Close
xlf.Close
theGrid = _gthm.GetGrid
YTemp = theGrid*0.AsGrid
```

```
if(File.Exists ("c \y.asc".AsFileName)) then
 File.Delete ("c \y asc".AsFileName)
end
YTemp.SaveAsAscii("c.\y.asc" AsFileName)
ylf = lineFile.Make("c:\y.asc".AsFileName,#FILE_PERM_READ )
yidt = lineFile Make("c:\yid asc".AsFileName,#FILE_PERM_WRITE )
data = ylf.ReadElt
yidt.WriteElt(data)
col = data.Extract (1) AsNumber
data = ylf ReadElt
yidt.WriteElt(data)
row = data.Extract (1).AsNumber
data = ylf.ReadElt
yidt.WriteElt(data)
data = ylf.ReadElt
yidt.WriteElt (data)
data = ylf.ReadElt
yidt.WriteElt(data)
data = ylf.ReadElt
yidt.WriteElt(data)
count = _fieldCellSize
count1 = _curRow * _fieldCellSize + _fieldCellSize
for each i in 0..(row-1)
data = ylf.ReadElt
buffer = ""
for each j in 0..(col-1)
a=-9999.asstring
if (i >= _curRow) then
  if(j >= _curCol) then
   a= count.AsString
   end
 end
if (i <= _curRow) then
  if(j >= _curCol) then
   a= count1.AsString
   end
 end
buffer = buffer+a+" "
end
yidt.WriteElt(buffer)
if (i >= _curRow) then
 count = count + _fieldCellSize
end
if (i <= _curRow) then
 count1 = count1 - _fieldCellSize
end
end
yidt.Close
ylf Close
_XGrid = Grid.MakeFromAscii("c:\xid.asc".AsFileName,false)
_YGrid = Grid.MakeFromAscii("c:\yid.asc" AsFileName,true)
```

'SCRIPT: SUM MANURE APPLIC ATION SITES (ha) AND FACILITY SITES
'PROGRAMMER. I.M CRAWFORD
'DATE: 1.99

```
theView = av.GetActiveDoc
ag = _ManGrd.GetGrid
ClSz = ag.GetCellSize
thevtab = ag.GetVTab
xV = theVTab.FindField( "Value" )
xb = theVTab.FindField( "Count" )
```

```
aSearch = "100" for each record in theVTab
v = theVTab.ReturnValueString(xv,record)
if (v=aSearch) then
b = theVTab.ReturnValueString(xb, record)
ha = ((b.AsNumber * ClSz)/100)
msgbox.info("There are"++ha.asstring++"ha suitable for manure application","Results")
end
end
theView = av.GetActiveDoc
theGrid = _FacGrd.GetGrid
aFileName = "temp.shp".AsFileName
if (File.Exists (aFileName)) then
  File.Delete (aFileName)
end
theResult = theGrid AsPolygonFTab(aFileName,TRUE,Prj MakeNull)
fthm = FTheme.Make(theResult)
anFTab = fthm.GetFTab
anFTab SetEditable(true)
_numFac = anFTab.GetNumRecords
msgbox info("There are"++_numFac asstring++ "sites suitable for siting a facility","Results")
```

ACKNOWLEDGEMENTS

I would like to thank my family for their love, support, and understanding as I follow my dreams and especially for their support in completing this task. Thank you for everything.

I would like to sincerely thank my friends and co-workers: Patrick Brown, Pipat Reungsang, and Sarah Stratton for their advice, constructive comments, and technical support in completing this project.

I would like to thank Marc Rogers for providing a great learning environment through the NRI project. My skills in GIS have increased a thousand-fold. Thanks for your patience.

I would also like to thank Kari Bartosiak, Mitch Marsolf, and Wayne Werne for their long-distance support and inspiration. I would especially like to thank Ms. Bonnie Whalen and Mr. Steve Anderson for introducing me to the area of GIS and giving me the opportunity to work in such an inspiring atmosphere. Thanks so much!

Finally, I would like to express my appreciation to my major professor, Dr. U. Sunday Tim, for his guidance during this study.